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THEORY

OF THE

GLACIERS OF SAVOY.

J. C. Brauner

THEORY

OF THE

GLACIERS OF SAVOY,

BY

M. LE CHANOINE RENDU,

(MÉM. DE LA SOCIÉTÉ ACADÉMIQUE DE SAVOIE, X. 95, 1841).

TRANSLATED BY

ALFRED WILLS, Q.C.

Late President of the Alpine Club.

TO WHICH ARE ADDED THE ORIGINAL MEMOIR; AND SUPPLEMENTARY ARTICLES

BY

P. G. TAIT, M.A.,

Professor of Natural Philosophy in the University of Edinburgh,

AND

JOHN RUSKIN, D.C.L.,

Professor of Fine Arts in the University of Oxford.

EDITED, WITH INTRODUCTORY REMARKS, BY

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54

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[*Reprint of the original Title page of M. Rendu's Memoir.*]

THÉORIE DES GLACIERS

DE LA SAVOIE.

PAR M. LE CHANOINE RENDU,

CHEVALIER DU MÉRITE CIVIL; SECRÉTAIRE PERPÉTUEL DE LA SOCIÉTÉ ROY. ACADÉM. DE SAVOIE.

Benedicite glacies et nives Domino.
DANIEL, Cant. *Trium puer.*

CHAMBÉRY:
CHEZ PUTHOD, IMPRIMEUR-LIBRAIRE.

1840.

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INTRODUCTORY REMARKS.

On the publication of the *Forms of Water*, at the end of 1872, it was with deep regret that I found certain allegations of anticipation by Bishop Rendu, and virtual plagiarism by Principal Forbes, reiterated by Professor Tyndall. I thereupon resolved to make a translation of Rendu's memoir, to be published without note or comment; because the scarcity of the work prevented most people from being able to discover for themselves how unfounded these allegations were. I had not advanced far in this matter when my friend Mr. Alfred Wills kindly offered to undertake the revision and completion of the translation. He has aimed at giving a fluent translation, which shall at the same time give correctly the very shades of meaning of the original. His intimate acquaintance with the glaciers of Savoy is a guarantee for its value. The original French is added, at his suggestion, for comparison in passages of doubtful meaning.

When, however, some months later, on my return from the Continent, I saw Professor Tyndall's pamphlet entitled *Principal Forbes and his Biographers*, I felt that more than this must be done. The continued repetition of an accusation, however groundless, leads many to believe in

its truth. I found that some who confided implicitly in my father's honour had been now led to imagine that he had not the right *altogether* on his side. To take up this matter gives me the keenest pain; and I am aware that many who have not examined the assertions of the other side very closely, or who may have been led astray by them, will at first blame me. But after due consideration I have arrived at a definite conclusion, and believe I am right when I refuse, either now or hereafter, to allow the very slightest shadow of an imputation upon my father's honour to pass unchallenged. This definite statement will, I believe, tend to stop those controversies which I, in common with my father, believed, from a silence of thirteen years on the one hand, and thirty on the other, to have been finally settled; but which, since my father's death, Professor Tyndall has thought fit to revive.

In October last, Mr. Ruskin's forcible remarks on the subject appeared in *Fors Clavigera* (Letter 34). A little later I heard that Professor Tait was preparing, in the name of the Biographers of Forbes, a complete examination of the question, to appear in the November number of the *Contemporary Review*, for which number he had been asked to prepare his reply. It appears, however, that after the article was in type it was deemed unsuitable by the Editor of the *Contemporary Review*. A proposal was therefore made to Professor Tait that he should incorporate his article in the volume which I was preparing. He expressed his willingness that this course should be followed.

Some of my father's non-scientific friends have told me that they could see no direct charges against him in the

Forms of Water. But the fact of the charges being indirect does not diminish their injuriousness, nor their power to mislead. In order to show the impression conveyed by that book to the mind of an impartial reader well versed in the history of the subject, Mr. Ruskin's letter is here re-published by his kind permission, together with an addition which he was anxious to make to it.

Principal Forbes stood by no means alone in the view he took of the character of Professor Tyndall's remarks on Rendu's theory, in the *Glaciers of the Alps.*

Dr. Lyon Playfair, for example, wrote the following letter, which, with a slight verbal alteration, he has given me leave to publish. It was written before Principal Forbes' *Reply* appeared :—

"EDINBURGH, *25th July, 1860.*

"MY DEAR PRINCIPAL,—I have carefully read Tyn-
"dall's chapters in regard to your labours, and compared
"them with the extracts of Rendu in your own work,
"and with the original of Rendu's memoir.

"The impression on my own mind is that you have
"done full justice to Rendu, and that in some respects your
"extracts are more to his honour than those of Tyndall.
"I allude especially to your referring the discrepancies in
"the measured motion of the glaciers to the difference of
"velocities in its parts. This reference has been omitted in
"Tyndall's quotation of your book, and is in my opinion
"a most serious omission. . . . .

"I do not think Tyndall would willingly do an unjust
"action, and if you like I will point out to him that the
"omission in question has to my reading the appearance of

"injustice, and request him to correct it in the next edition "of his book. His work is sure to go through various "editions, and it would be important to get your case "honestly before the public. Differences of opinion are of "course a matter of fairness; but imperfect quotations, "involving as in this case an incomplete statement of your "remarks, require removal from a book like Tyndall's."

The force of Principal Forbes' *Reply** was admitted by all. For example, Mr. E. W. Hemming, of Lincoln's Inn, wrote as follows:—

"*8th November, 1860.*

"DEAR SIR,—I find upon my table your pamphlet in "answer to part of Tyndall's book. I am very glad you "have published it, as it strikes me as a complete refut- "ation." . . . .

M. Studer, of Berne, wrote thus, Oct. 3rd, 1860:—

"Aujourd'hui même je viens de recevoir et de lire votre "*Reply to Mr. Tyndall.* Les *Glaciers of the Alps* ne me "sont pas encore parvenus, mais d'après les extraits que "vous en donnez, je ne puis douter que l'auteur n'ait pas "été ni juste ni bienveillant envers vous. Votre réfu- "tation du reste est victorieuse et ne souffre pas de "réplique."

I need hardly say that these letters, selected from a large correspondence, are here introduced, not as testimonials in favour of my father (for which I am well aware there could be no necessity), but in support of my view of the strength of the evidence.

* Republished as an Appendix to the *Life and Letters of James David Forbes.*

Sir William Thomson expressed his opinion in the following terms:—

"I have read your reply to Tyndall's remarks, and I "think it must be satisfactory to every unprejudiced "person. . . . .

"Your reply merely confirms (not, I believe, at all "extending) the impression I had formed of Rendu's "ideas and writings from your own book" [*the Travels*]. "I believe no candid person who had read your book "could for a moment entertain the idea that you had not "done ample personal justice to Rendu, and *set off* his "ideas most advantageously with reference to the true "theory, so as in fact to connect him in the minds of "your readers even more decidedly with the viscous "theory as a scientific truth, than the manner in which "he expressed them required, or than he himself would "have expected as his unquestionable right."

The arguments in my father's reply of 1860 have not been in the least affected by Professor Tyndall's late rejoinder, and I leave the analysis of it in Professor Tait's hands, who has examined the evidence in a thorough and searching manner, and exposed its fallacies by a critical examination of the question, which is unanswerable. But I cannot close these remarks without pointing out a few of the passages in that pamphlet where Professor Tyndall has misrepresented the facts of the case, and which Professor Tait has not commented upon. The most important are to be found in his interpretation of the word *crevasse* as used by Rendu, and in his remarks on my father's conduct towards Agassiz. These will suffice to indicate the manner in which Professor Tyndall has attempted to support his course of action.

CREVASSES.

Professor Tyndall says, at p. 25 of his Pamphlet, that Bishop Rendu would apply the term crevasses to "the "depressions of the wrinkles discovered by Principal "Forbes on the Glacier du Géant, which turn their con- "vexities downwards. These wrinkles eventually disap- "pear, but they leave behind them the very Dirt-Bands "which suggested so strongly to Principal Forbes the "idea of semifluid motion." This assertion is the main-stay of the Pamphlet, but I object to this interpretation of Rendu's meaning upon several grounds.

1. Rendu says he keeps for certain features of the ice "le nom de crevasses, *qu'on leur a toujours donné.*"

2. Rendu's observation was made opposite the Mont Envers, at which point the *depressions of the wrinkles have vanished altogether.*

3. Speaking of the Glacier des Bois, opposite the Mont Envers, Rendu says "*Ici point de rupture, car ces crevasses ne sont pas les fentes desquelles nous avons parlé plus haut.*" From which it appears that the well known crevasses in that region receive the name *crevasses* from Rendu.

4. At pp. 106 and 110 of this work Rendu most clearly describes the appearance of the crevasses at this spot, and gives a sketch to illustrate his meaning, which shows them to have been true crevasses, and not depressions of the wrinkles.

5. At p. 42 of the *Glaciers of the Alps* Professor Tyndall described these same crevasses as seen at this same spot. He did not say that they have their convexity downwards. But he now says so, and that he

knew it in 1860! Nor did he then allow that they have any connection with the wrinkles. He said that they owe their origin to the glacier having passed over a convexity of its bed.

6. Professor Tyndall, in the same passage, gave a sketch of the crevasses, &c., at the spot referred to, which exactly resembles Rendu's sketch.

7. P. 302 of the *Glaciers of the Alps* shows that Professor Tyndall then admitted that Rendu was really describing the same crevasses as he had described at p. 42, and not the wrinkles.

8. Rendu's division of the ice fissures into fentes and crevasses is the same as Principal Forbes'. In the *Philosophical Transactions* Forbes says that the study of crevasses requires a twofold classification into crevasses which may be considered as proper to the mass of the glacier, and those which merely seam its surface (*Occasional Papers*, p. 151). He then goes on to explain that the one class are caused by differential motion, the other by irregularities in the bed. It appears, then, that Rendu meant by *crevasses* exactly what Forbes meant by that word; and that Forbes was quite aware of the distinction between *fentes* and *crevasses*.

FORBES' CONDUCT TOWARDS AGASSIZ.

In his late pamphlet Professor Tyndall informs us (p. 6) that if M. Agassiz was not quite wrong in his controversy with Principal Forbes, then the conduct of the latter, after visiting M. Agassiz on the Aar glacier in 1841, in proceeding to make observations on the physical part of the subject in 1842, cannot be justified. Now, whilst I cannot admit that M. Agassiz was not quite wrong in that

controversy, I must yet draw Professor Tyndall's attention to one or two facts :—he seems to forget (1.) that the measurements of motion of the Aar glacier were made at Principal Forbes' suggestion ; (2.) that before the visit of Principal Forbes to the Aar glacier, M. Agassiz made no such observations ; (3.) that Principal Forbes published, in the *Edinburgh Review* for April, 1842, the methods which he considered suitable for glacier measurements; and (4.) that after all this he made the required measurements on the Mer de Glace. He was thus the first to determine the greater motion of the centre, among other equally important facts. On this last point Professor Tyndall gives an equal claim to M. Agassiz ; and blames Principal Forbes for not doing the same. He says (*Forms of Water*, § 150) that M. Agassiz, in 1842, measured the displacements of *six* staves driven into the ice in 1841 ; and in his pamphlet, Professor Tyndall adds (p. 6) that he has verified the statement by reference to the *Comptes Rendus* and finds that the observations of Agassiz take date from August 1st. Now, in the first place, this is the date when he wrote his letter, and the date of Forbes's letter announcing the greater central motion was July 4th. In the second place, if the reader will kindly refer to the *Comptes Rendus* above alluded to (which bears date August 29th, 1842), he will find that Agassiz simply gives, without comment, the measured rates of *three* stakes ; the other three were not announced until 1847, in his *Nouvelles Etudes*. And although in the same paragraph of the *Comptes Rendus* Agassiz points out that the greater wasting at the sides of the glacier is opposed to his theory, he does not even allude to the fact that the greater central motion is in direct opposition to his often ex-

pressed theory of the greater motion of the sides. The slight allusion to this measurement, and his suppression of three of the observations, show that he did not accept it as a scientific truth, and was of opinion that future observations might be found to support his erroneous theory. This view of the case is justified when we learn from the *Nouvelles Etudes* (p. 454) that *after* the above observations he was in doubt as to the universality of the law. Further, no member of the Agassiz party publicly allowed the generality of the law until, in the *Comptes Rendus* for 1844, December 9, M. Desor admitted this fact in a letter to M. Elie de Beaumont. Principal Forbes was, therefore, quite justified in using the word *now*, to which Professor Tyndall objects, in the following passage :—"It is hardly "necessary to premise that M. Agassiz and his friends "now admit that all glaciers move fastest at the centre "and slowest at the sides," (Ninth Letter on Glaciers, 1845, March 7.)*

THE COPLEY MEDAL IN 1859.

In 1859 it was proposed in the Council of the Royal Society that Principal Forbes should receive the Copley Medal in acknowledgment of his labours on the glacier question. The medal was, however, awarded to Weber, a distinction which he richly deserved, and which, I am sure every one must say, was well bestowed. But it has been hinted (*Nature*, 1873, May) that the reason why it

* After this and all other mention of Agassiz' name in the present volume (with the exception of the allusions by Mr. Watson, p. 209) was in the printer's hands, the sad news of his death has reached us. I believe that nothing will be found in these pages which is not strictly and exactly correct concerning that controversy, into which he was led by his confidential adviser, M. Desor. Professor Tyndall would have done well to leave it in that oblivion to which M. Agassiz consigned it for thirty years, and from which it must have distressed him to see it resuscitated by a third party.

was not given to Forbes was the reading of a paper at a Council meeting, which stated, among other things, that he had done scant justice to Rendu. If this be so, it is not my duty to discuss the matter. If it be alleged that a single vote was influenced by such a statement, it is a matter for the Council of that venerable body, and not for me, to investigate. I bring the matter forward in consequence of a remark by Professor Tyndall in his pamphlet. He says (p. 32), "Had the rules of good taste been observed, he" [Forbes] "would have known nothing of these discussions." . . This may be true; but if so, the breach of good taste lay on the part of those who brought forward objections before the Council only a few days before their final decision. This is explained in the following letter:—

On the 28th Oct., 1859, Whewell wrote as follows:—

"My Dear Forbes,—I want information from you "relative to the history of Glacier Theory. I proposed "you as a fit and proper person to receive the Copley "Medal, and yesterday I was unexpectedly opposed "by the assertion that M. Rendu had propounded the "leading points of a theory nearly identical with yours, "before you promulgated yours. Of course, I am "aware of what you have said of M. Rendu; but "I have not seen his book, and should be very glad "to see it before the discussion comes on again. ——, "who is a member of the Council, read a paper drawn "up by Huxley, in which there was an elaborate state-"ment of M. Rendu's assertions in which he was sup-"posed to have anticipated you; and on his having "declared that the middle of the glaciers moves faster "than the sides, that the motion of a glacier is of the

"same kind as the motion of a river, and that the ice "is in a certain sense plastic. He noticed also the pas- "sages in which you had referred to M. Rendu, and con- "sidered your acknowledgment as insufficient. Of course "my reply was that you were not acquainted with M. "Rendu's labours when you formed your theory, that he "discovers who proves, and that, so far as I know, M. "Rendu's views were rather conjectures than general "views formed by measurements, as yours were. But, as "I said, I wish to see M. Rendu's book before the subject "is again discussed. Something also was said of Rendu "having noticed the laminal structure of the ice; and a "passage in your preface to your last published collection "of papers was quoted as if you had claimed an undue "approximation to Tyndall's views. To this I could only "reply that your views did seem to come very near to his, "except that he spoke of *regelation*, while you spoke of "*cohesion* as reconstituting the mass. But Huxley in his "paper insisted that there was a great difference between "you and T——. It is plain that there is a strong feeling "among Tyndall's friends, and that they will oppose me. "But I should like to be able to speak of Rendu's work "clearly and distinctly. In the meantime you see that "your discoveries have passed from the stage when people "say they are not true to the next stage when people say "they are not new! and the truth of your theory is "allowed, and of course your services as having discovered "and published it, whatever M. Rendu may have done "before; but that is principally what I want to "acquaint myself with. I have not a copy of Huxley's "paper; it was in MS., and, as I have told you, read by "——. I should like to have some answer ready by

"next Thursday, when, as I suppose, the decision of the "medal must take place. Probably you have Rendu's "book. Could you give me a notice what is the tone and "purport of it. How far his views are conjectural, and "how far they are supported by definite evidence. How "far he has applied them to glaciers in general, and so on. "Of course his priority, to whatever extent it may go, does "not affect your originality, nor your place in the history "of English science on this subject. But this assertion of "a prior promulgation of a like theory by another will, I "think, weigh with several of the Council." The letter concludes by protesting against the animus which led to such an objection being raised suddenly, when there was hardly time to answer it.

When this letter arrived my father despatched Rendu's memoir to Dr. Whewell at Cambridge, by return of post; but it arrived too late to be of use. He was convinced that this was the most complete answer that could be given to such allegations. With precisely the same feelings do I now give to the public the first opportunity they have had of consulting the memoir.

INTRODUCTION TO RENDU'S MEMOIR.

The accompanying translation is published with the view of allowing Bishop Rendu and Principal Forbes each to have such credit as may be due to him; and of showing how fully Principal Forbes brought Rendu's labours before the world by reference to them in *The Travels*. There are not, I believe, more than two or three copies of the original in the British kingdom at present.

I hold a high opinion of the general accuracy and depth of thought displayed by the writer, the more so since these are combined with a desire to explain phenomena by existing causes. But these qualities are shown more in the general descriptions (such as his explanation of the mountain breezes, his proofs that glaciers move, and that stream glaciers are physically connected with glacier reservoirs) than in any attempt at proving the mode of motion of glaciers. Professor Tyndall has always unduly exalted Rendu's more happy speculations, cast a veil over his less fortunate conjectures, and left unnoticed the fact that in many cases these ideas were thrown out in the form of vague suggestions. He has, on the other hand, reduced the value of Forbes' work to a minimum; as in the *Glaciers of the Alps*, where he sums up Forbes' contributions to the viscous theory in two pages; or in the *Forms of Water*, p. 161, where he says that to the *advocacy* of Principal Forbes the *public knowledge* of the viscous theory is mainly due.

Principal Forbes' claims to having established a viscous or plastic theory of glaciers rest mainly upon the following observations made by him:—Neglecting the obvious facts of the moulding of the glacier to its bed, its compression and swelling, we have—

1. The motion of the ice is continuous.
2. The centre moves faster than the sides.
3. This change of velocity is continuous.
4. The variation of velocity in the breadth of a glacier is proportional to the absolute velocity, at the time, of the ice under experiment.
5. The velocity of a glacier increases when the steepness of its bed increases.

6. A continuous mass of ice on the Brenva became distorted without the formation of any crevasses.

7. The greater the heat and rainfall, the more liquid is the ice, as shown by its greater velocity.

8. The melting of the surface in summer is compensated by a thickening (resulting from diminished fluidity in the viscous mass) in winter.

9. In cases where the tenacity of the ice is insufficient to bear the strain crevasses are formed.

10. These crevasses, and also the broken continuity of the whole mass, are closed up by time and cohesion.

11. The differential motions of a viscous mass account for the veined structure.

12. In every respect, experiments on viscous substances show motions similar to those of glaciers.

No wonder then that Professor Tyndall admits (perhaps unwittingly) that "it is undoubted that the glacier moves like a viscous body." (*Forms of Water*, p. 163.) But Principal Forbes could not with justice be asked to give Rendu or any one else credit for the above observations which he himself was the first to make. Rendu did not claim to explain the cause of motion of glaciers, nor to have made measurements which could lead to a theory; and it is unfortunate that Professor Tyndall should have thought that he could increase Rendu's credit by straining his words, and supporting his view by imperfect quotations (four of which are alluded to in Forbes' *Reply*), so as to give him more than either he wished for or deserved.

It may, perhaps, be said that greater clearness would have been given to this work by adding to it a reprint of the *Reply* written by Principal Forbes in answer to

some of Professor Tyndall's objections. This may be true; but the *Reply* has lately been reprinted as Appendix A to the *Life and Letters of James David Forbes* (Macmillan & Co., 1873). I conceive that it is more in accordance with the object of this volume to reprint only that article of the *Reply* in which Principal Forbes cited the passages in his writings where he had referred to, or quoted from, Bishop Rendu. This extract will be found at the end of the present volume. Let the reader, after he has studied Rendu's interesting memoir, turn to the end of the book and consult the account of Rendu's views, given by Principal Forbes in his writings up to 1846. He will then be able to judge whether Professor Tyndall was justified in saying that it devolved on him (Professor Tyndall) to call attention to passages in the memoir, of "cardinal import," "overlooked" by previous writers, "nearly twenty "years after their publication." After such an investigation, the reader will be more likely to come to the conclusion arrived at by Sir William Thomson, namely, that Principal Forbes "had done ample per- "sonal justice to Rendu, and *set off* his ideas most "advantageously with reference to the true theory, so "as in fact to connect him in the mind of the reader "even more decidedly with the viscous theory as a "scientific truth, than the manner in which he ex- "pressed them required, or than he himself would have "expected as his unquestionable right."

In conclusion, I ought perhaps to state that, in accordance with an engagement entered into in 1871, I must leave this country in June next for the Sandwich Islands, to make observations on the approaching tran-

sit of Venus. Should the publication of this volume draw forth remarks which I ought to answer, the reason of my temporary silence will be understood. Yet I cannot conceive that this is likely to happen. Misunderstanding is possible only so long as the data required for its correction are not generally accessible. This is no longer the case. The controversy is now concluded; and an unbiassed judgment will, I feel sure, be given by the scientific world, and the general public.

GEORGE FORBES.

RENDU ON GLACIERS.

PREFACE.

I HAD almost abandoned the idea of publishing this work, which was completed nearly two years ago, when I saw the announcement of the *Notice sur les Glaciers, &c.*, of M. Ch. Godefroi. The sight of this title alone sufficed to make me change what had been a doubt into a settled resolution. I read the work of M. Godefroi, and as I finished it I said, "My theory shall appear; all imperfect as it is, the theories of M. Godefroi render it necessary." This natural philosopher has said nothing of the most curious phenomena presented by glaciers. The crevasses, their depth, their form, the wells, the cracks, the inequalities of the surface, the convex form of the glaciers, the velocity of the flow of the ice, the rocks disgorged by the glacier, all this remains to be examined; the question

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AVERTISSEMENT.

J'avais presque renoncé à la publication de cet ouvrage, qui est achevé depuis près de deux ans, quand j'ai vu paraître la *Notice sur les Glaciers, etc.*, de M. Ch. Godefroi. La seule vue de ce titre a suffi pour me faire changer en résolution déterminée ce qui n'était encore qu'une hésitation. J'ai lu le travail de M. Godefroi, et en le finissant, j'ai dit: ma théorie paraîtra; tout imparfaite qu'elle soit, les systèmes de M. Godefroi la rendent nécessaire. Ce savant n'a rien dit des phénomènes les plus curieux que présentent les glaciers. Les crevasses, leur profondeur, leur forme, les puits, les fentes, les rubosités de la surface, la forme convexe des glaciers, la vitesse de l'écoulement des glaces, les rochers revomis par le glacier, toute celà reste à examiner; la question est presque encore

is still almost untouched. Nor is this all: the state of things imagined by M. Godefroi in order to explain the formation of moraines appears to me so contrary to observation and to the very nature of moraines, that I believe it to be necessary to submit once more to naturalists the explanations already given by others, whilst rendering them clearer by new observations, and I may also say by the impossibility of the cause assigned by M. Godefroi.

Before visiting the glaciers, I had studied all that physicists, naturalists, and travellers had written on this great phenomenon of nature. I had admitted provisionally only the explanations which they gave of all the peculiarities which attend it; but from the moment I could see for myself the principal glaciers that surround Mont Blanc, those of the Valais and of the Simplon, I felt convinced that everything had not been observed, and that the causes assigned to the phenomena were not always correct.

Had the special knowledge of glaciers been the specific object of the travels of De Saussure, this learned observer would have left nothing to be said by

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toute entière. Ce n'est pas tout: le système imaginé par M. Godefroi pour expliquer la formation des moraines me paraît tellement contraire à l'observation et à la nature même des moraines, que je crois nécessaire de remettre sous les yeux des naturalistes les explications déjà données par d'autres, en les rendant plus évidentes par de nouvelles observations, et je dirai même par l'impossibilité de la cause assignée par M. Godefroi.

Avant de visiter les glaciers, j'avais étudié tout ce que les physiciens, les naturalistes et les voyageurs avaient écrit sur ce grand phénomène de la nature. Je n'avais que provisoirement admis les explications qu'ils donnaient sur toutes les particularités qui l'accompagnent; mais dès l'instant où j'ai pu voir par moi-même les principaux glaciers qui entourent le Mont-Blanc, ceux du Valais et du St-Plon, j'ai cru reconnaître que tout n'avait pas été observé, et que les causes assignées aux phénomènes n'étaient pas toujours vraies.

Si les voyages de Saussure avaient eu pour but la connaissance spéciale des glaciers, ce savant observateur n'aurait rien

those who come after him; but as he speaks of them merely in an accidental way, it is not surprising that it should still be possible to touch upon a subject which nevertheless owes much to him, as will be seen by the aid that his writings have given me, and by the numerous quotations that I shall be obliged to make from them.

It is at the Glacier des Bois, upon the Mer de Glace, at the Glacier des Bossons, and at that of Argentière, that my principal observations have been made. It is to them, therefore, that the reader must recur in order to come more easily to understand the causes that I shall assign to the different phenomena. I am aware that nature is as immense in her variety as in her extent; but she always resembles herself in the production of identical phenomena. Those which to us wear the aspect of anomalies seem to deviate from the simplicity of known laws only by reason of the complication of their causes, accidents of soil, relative position, and the like.

The sum total of the facts met with on the glaciers has appeared to me to be of great simplicity; they flow almost all the one from the other, and are

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laissé à dire à ceux qui viennent après lui ;mais comme il n'en parle qu'accidentellement, il n'est pas étonnant que l'on puisse revenir sur un sujet qui pourtant lui doit beaucoup, comme on le verra par les secours que m'ont fourni ses ouvrages, et par les citations nombreuses que je serai forcé d'en tirer.

C'est au glacier des Bois, sur la mer de glace, au glacier des Bossons, à celui d'Argentière que mes observations principales ont été faites. C'est donc là que le lecteur devra se reporter pour arriver plus facilement à l'intelligence des causes que j'assignerai aux divers phénomènes. Je sais que la nature est aussi immense dans sa variété que dans son étendue; mais elle est toujours semblable à elle-meme dans la production des phénomènes identiques. Ceux qui se montrent à nous comme des anomalies, ne semblent sortir de la simplicité des lois connues que par la complication des causes, les accidents du sol, la position relative, etc....

L'ensemble des faits qui se rencontrent sur les glaciers m'a paru d'une grande simplicité; ils découlent presque tous les

evidently deducible from the knowledge furnished to us by the laws of physics. My sole aim in embodying my observations in a theory, which I seek to render as complete as the feebleness of my lights will allow me, is to place the study of glaciers within the reach of everyone. Even though the explanations that I shall give should not be looked upon by natural philosophers as incontrovertible, I should still trust to have rendered some service to truth in adding to the elements which must aid its discovery; and if the moments I have consecrated to this labour should be useless to others, they will not have been so to myself; the study of nature always makes a better man of him who contemplates her with an unbiassed spirit and an upright and disinterested heart. It is one of the thousand paths that lead to God. Yes, to seek to know His daily action in the administration of this vast universe which is His work, is to place one's self under the necessity of praising Him. *Fire, hail, snow, ice, stormy wind fulfilling His word . . . . . let them praise the name of the Lord.* Ps. cxlviii.

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uns des autres, et se déduisent évidemment des connaissances que nous fournissent les lois de la physique. Mon unique but en consignant mes observations dans une théorie, que je cherche à rendre aussi complète que me le permettra la faiblesse de mes lumières, est de mettre l'étude des glaciers à la portée de tout le monde. Alors même que les explications que je donnerai ne seraient pas regardées comme incontestables par les savants, je croirais encore n'avoir pas été inutile à la vérité en ajoutant aux éléments qui doivent aider à la trouver; et si les moments que j'ai consacrés à ce travail étaient inutiles pour les autres, ils ne le seraient pas pour moi; l'étude de la nature rend toujours meilleur celui qui la contemple avec un esprit juste et un cœur droit et désintéressé; c'est une des mille voies qui conduisent à Dieu. Oui, c'est se placer dans la necessité de le louer que de chercher à connaître son action journalière dans l'administration de ce vaste univers qui est son ouvrage. — *Ignis, grando, nix, glacies, spiritus procellarum quæ faciunt verbum ejus... laudent nomen Domini.* Ps. 148.

CHAPTER I.

OF GLACIERS IN GENERAL.

WHEN the height of mountains exceeds ten or eleven thousand feet above the level of the sea, their summit usually remains covered with snow during all seasons. This snow, more or less hardened by weather, assumes the appearance, the hardness, and sometimes the colour of ice, and we give to the whole mass the name of glaciers.

Nevertheless, in common parlance, the name of glacier is more specially given to those portions which descend below the region of perpetual snow, and display themselves in the midst of the vegetation of the high valleys. It is, therefore, necessary to distinguish two kinds of glaciers. I shall give the name of *reservoir glaciers* to those of the higher regions in which their formation must be continuous, because the

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CHAPITRE PREMIER.

DES GLACIERS EN GÉNÉRAL.

Quand la hauteur des montagnes dépasse dix à onze mille pieds au-dessus du niveau de la mer, leur sommet reste ordinairement couvert de neige pendant toutes les saisons. Cette neige, plus ou moins durcie par le temps, prend l'aspect, la dureté, et quelquefois la couleur de la glace, et l'on donne à l'ensemble le nom de glaciers.

Pourtant, dans l'usage ordinaire, on donne plus particulièrement le nom de glaciers aux parties qui descendent au-dessous de la région des glaces, et viennent se montrer au milieu de la végétation des hautes vallées. Il est donc nécessaire de distinguer deux espèces de glaciers. Je donnerai le nom de *glaciers-réservoirs* à ceux des régions supérieures, où la formation doit être continue, parce que la température de ces lieux est

temperature of those parts is habitually below the freezing point. To those which descend into the region of vegetation where melting of ice and snow takes place during a considerable part of the year, as they have evidently a different origin from the first, I shall give the name of *stream glaciers.*

One feels that it would be difficult, not to say impossible, to establish with precision the line which separates these two regions. From the point where melting is nothing to that where it is exactly sufficient to cause the disappearance during the summer of all the ice or all the snow that has accumulated during the winter, there are several zones of differing temperature, but in none is the heat in excess of the cold. Similarly from the point of complete melting down to that of the growth of the vine, for instance, there are also several zones of differing temperature, and in none is the cold in excess, so as to render snow or ice perpetual. This boundary line, which is still called the limit of perpetual snow, is not always in direct proportion to the vertical elevation. It rises or falls according to several circumstances, which are not everywhere the same. The

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habituellement au-dessous de zéro. Pour ceux qui descendent dans la région végétale où la fusion des glaces et des neiges s'opère pendant une partie considérable de l'année, comme ils ont évidemment une autre origine que les premiers, je les appelerai *glaciers d'écoulement.*

On sent qu'il serait difficile, pour ne pas dire impossible, d'établir avec précision la ligne qui sépare ces deux régions. Du point où la fusion est nulle jusqu'à celui où elle est précisément suffisante pour faire disparaître pendant l'été toute la glace ou toute la neige qui s'est accumulée pendant l'hiver, il y a plusieurs zones de température diverse, mais dans aucune la chaleur n'est en excès sur le froid. De même depuis le point de fusion totale jusqu'à celui de la végétation de la vigne, par exemple, il y a aussi plusieurs zones de température diverse, et dans aucune le froid n'est en excès de manière à rendre la neige ou la glace perpétuelle. Cette ligne intermédiaire, que l'on a continué d'appeler limite des neiges perpétuelles, ne saurait être toujours en rapport direct avec l'élévation verticale; elle s'élève ou s'abaisse d'après plusieurs circonstances qui ne

slope of the ground relatively to the sun, the form and nature of the soil, the degree of latitude, the elevation of the plateau generally upon which the mountain rests, may largely modify its position. I shall here present a picture of the seven Alpine regions as naturalists have drawn it. The vine reaches to 1,700 feet above the level of the sea, the region of the oak to 2,800 feet, the region of the beech to 4,000 feet, that of the coniferæ to 5,500 feet, that of the graminiferæ to 6,500 feet and more. At 7,500 feet we find in the middle of summer isolated masses of snow, and the ground is uncovered wherever it is not sheltered from the sun; it is here that arctic plants are found. Lastly, above 8,000 feet come the eternal snows. This limit seems to me, so far as the Alps are concerned, placed too low; for all travellers agree that at this height and even higher we still meet with saxifrages, gentians, chrysanthemums, and some other plants of arctic climates; it follows that if this zone had nothing above it, there would be in summer some days when it would be entirely free from snow. We must therefore put the

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sauraient être les mêmes partout. La pente du terrain relativement au soleil, la forme et la nature du sol, le degré de latitude, l'élévation du plateau général sur lequel repose la montagne peuvent apporter de grandes différences dans sa position. Je vais placer ici le tableau des sept régions alpines tel que l'ont tracé les naturalistes. La vigne s'élève jusqu'à 1,700 pieds au-dessus du niveau de la mer, la région des chênes jusqu'à 2,800 pieds, la région des hêtres jusqu'à 4,000 pieds, celle des cônifères jusqu'à 5,500 pieds, les graminées jusqu'à 6,500 pieds et plus. A 7,500 pieds on trouve dans le milieu de l'été des amas de neige isolés, et le sol est découvert partout où il n'est pas abrité du soleil; c'est là que se trouvent les plantes hyperboréennes. Enfin au-dessus de 8,000 pieds viennent les glaces éternelles. Cette limite me paraît même, pour les Alpes, placée trop bas; car tous les voyageurs conviennent qu'à cette hauteur et même au-dessus on rencontre encore des saxifrages, des gentianes, des chrysanthèmes et quelques autres plantes des climats hyperboréens; il s'ensuit que si cette zone n'était nullement dominée, il y aurait dans l'été quelques jours où elle serait entièrement dépouillée de neige. Il faut donc

limit of perpetual snow a little higher; I should place it at 9,000 feet. It is there that the line of separation between *reservoir glaciers* and *stream glaciers* is to be found.

CHAPTER II.

OF RESERVOIR GLACIERS.

THE rays of the sun fall in vain on the summit of Mont Blanc, at a height of 14,700 feet above the level of the sea; the snow does not melt there. M. de Saussure having reached this, the highest point of Europe, on the 2nd of the month of August, found the thermometer at 26°·8 Fahr.,* and even in the sun it was more than a degree below the freezing point, while in the plain it was 81°·2. At the station from which he had started that morning, which is more that 3,000 feet lower, he had

* The temperatures given by M. Rendu are generally in Réaumur's scale. In the translation these are all reduced to Fahrenheit's scale. Measurements of length have not been altered, and remain in *French* feet. —ED.

porter un peu plus haut la limite des neiges perpétuelles; je la suppose à 9,000 pieds. C'est là que se trouve la ligne de séparation entre les *glaciers-réservoirs* et les *glaciers d'écoulement.*

CHAPITRE II.

DES GLACIERS-RÉSERVOIRS.

La crête du Mont-Blanc, à 14,700 pieds au-dessus du niveau de la mer, est inutilement frappée des rayons du soleil; la neige n'y fond pas. M. de Saussure arrivé sur ce point culminant de l'Europe au 2 du mois d'août, trouva le thermomètre de Réaumur à — 2°.3, et même au soleil il était à plus d'un degré au-dessous de zéro, tandis que dans la plaine il était à +22°. Dans la station d'où il était parti le matin, laquelle se trouve plus de trois mille pieds plus bas, il avait compté trois

noted 25°·7. M. de Tilly, who made his ascent on the 8th of October, found at the summit of Mont Blanc a temperature of about 0°. Two other travellers, who were surprised by a tempest and detained at the rocks of the Grands Mulets, experienced after the storm 32° of frost in the month of August. All observations that have been made agree in demonstrating that the melting of snow is absolutely *nil* on this summit.

Nevertheless, it is right to state that M. de Saussure, who is an authority, and I may say almost an oracle when we are dealing with the phenomena of this mountain, which he has (so to speak) conquered to science — M. de Saussure has recourse to melting to explain the formation of a thin layer of ice which covers the snow and breaks beneath the foot of the traveller. It is a pure inadvertence on the part of the philosopher of Geneva; to explain this phenomenon, there is another cause perpetually at work—the condensation of vapours—which, as we shall see elsewhere, must be very great in this locality.

At the moment when snow first falls on great ele-

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degrés au-dessous de zéro. M. de Tilly, qui a fait son ascension au 8 octobre, a trouvé au sommet du Mont-Blanc une température de 14 ou 15 degrés au-dessous de zéro. Deux autres voyageurs, que la tempête a surpris et arrêtés aux rochers des Grands-Mulets, ont éprouvé après l'orage un froid de 14° au mois d'août. Toutes les observations qui ont été faites sont d'accord pour démontrer que la fusion des neiges est absolument nulle sur cette sommité.

Pourtant il faut le dire, M. de Saussure qui est une autorité, et je dirai presque un oracle quand il s'agit des phénomènes de cette montagne qu'il a pour ainsi dire conquise à la science, M. de Saussure a recours à la fusion pour expliquer la formation d'une mince lame de glace qui recouvre la neige et qui se brise sous le pied du voyageur. C'est pure inadvertance de la part du savant Genevois; il y a pour expliquer ce phénomène une autre cause perpétuellement agissante, c'est la condensation des vapeurs qui, comme nous le verrons ailleurs, doit être fort grande dans cette localité.

Au moment où la neige tombe sur les grandes élévations, elle

vations, it is ordinarily in the state of powder; in a short time, penetrated by the vapours which are always in abundance about very lofty summits, it hardens on the surface.

It may possibly be, also, that the layer of ice which is found there, like that which is met with often enough on the snow of the plains, is the result of rain falling and freezing on coming into contact with the snow.

The effect of the greatest heat which is experienced on heights far inferior to those of Mont Blanc consists in softening it so as to give to its different parts more facility for uniting with one another; and to get so far as melting, we must have a certain concurrence of circumstances which can rarely present themselves—a hot wind, aided by the sun, or humidity at a somewhat high temperature.

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est ordinairement en état de poussière; peu après, pénétrée par les vapeurs toujours abondantes autour des plus hautes sommités, elle se durcit à la surface.

Il serait possible aussi que la couche de glace qui a été trouvée là, comme on la rencontre assez souvent sur la neige des plaines, eût été le résultat de la pluie tombée et congelée en arrivant au contact de la neige.

L'effet de la plus grande chaleur qui se manifeste sur des hauteurs bien inférieures à celles du Mont-Blanc, consiste à la ramollir de manière à donner à ses diverses parties plus de facilité à s'unir, et pour pousser jusqu'à la fusion, il faudrait un certain concours de circonstances qui doivent rarement se présenter: ce serait un vent chaud, aidé par le soleil, ou de l'humidité à une température un peu élevée.

CHAPTER III.

CAUSES OF INCREASE IN THE RESERVOIR GLACIERS.

First Cause: Snow.

Snow is, beyond dispute, the most abundant means employed by nature to maintain reservoirs of ice; it falls upon them at all seasons of the year; that which in the plain comes down in the form of rain, falls most commonly on these heights in the form of snow; and if in ordinary seasons it is not uncommon to see as much as 400 inches of snow-fall in the course of one year in the high valleys of the Alps, it must be conceived that the quantity must be very considerable also on the highest points of the eternal snows.* It

* According to the *Annuaire des Observations Météorologiques, faites à St. Jean de Maurienne* by Dr. Mottard, there fell, in 1836, 72 inches of snow, and 25 inches of water at the bottom of the valley.

The observations of M. Venetz, of the Valais, engineer, give 40 feet 10 inches 4½ lines as the snow-fall in the valley of Bagnes, in each of the years 1818, 1819, 1820, 1821, and 1822.

CHAPITRE III.

CAUSES D'ACCROISSEMENT DES GLACIERS-RÉSERVOIRS.

Première cause: la neige.

La neige est sans contredit le moyen le plus abondant employé par la nature pour entretenir les réservoirs de glace; elle y tombe dans toutes les saisons de l'année; ce qui, dans la plaine, arrive sous la forme de pluie, tombe le plus ordinairement sur ces hauteurs sous la forme de neige, et si, dans les saisons ordinaires, il n'est pas rare de voir tomber dans les hautes vallées des Alpes jusqu'à 400 pouces de neige dans le cours d'une année, on doit concevoir que cette quantité doit être bien considérable aussi sur les sommités des glaces éternelles.* Cependant il est

* D'après l'Annuaire des observations météorologiques faites à St-Jean-de-Maurienne par M. le docteur Mottard, il est tombé en 1836 72 pouces de neige, et 25 pouces d'eau au bas de la vallée.

Les observations de M. Venetz, ingénieur en Valais, portent à 40 pieds 10 pouces 4 lignes et demie la neige tombée pendant chacune des années 1818, 1819, 1820, 1821 et 1822, dans la vallée de Bagnes.

is very probable, however, that less of it falls on the loftiest peaks than in the surrounding valleys, for two reasons—the first is, that at this height in the atmosphere vapours are not susceptible of acquiring the degree of density that they possess lower down; the second is, that a considerable part of the snow which falls upon the top of high mountains is carried away by the winds, and forms an addition to what falls in the valleys.

Second Cause: Rain.

It is a fact, brought to light by meteorological observations, that rain is in general more abundant in lower than in higher regions. Without claiming for the observation the precision that science demands, there are few travellers accustomed to mountaineering who have not been witnesses to this fact. Often, from the top of a mountain where the wayfarer is enjoying a clear sky and a burning sun, he may hear the rolling of thunder below, and see the clouds spread and discharge themselves upon the plains. On the other hand, travellers have often been surprised by rain

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bien probable qu'il en tombe moins sur le crêtes les plus élevées que dans les vallées qui sont autour, pour deux raisons: la première est que vers cette hauteur atmosphérique les vapeurs ne sont pas susceptibles d'acquérir le degré de densité qu'elles ont plus bas; la seconde est qu'une assez grande partie de la neige qui tombe sur la cime des hautes montagnes est emportée par les vents, et vient s'ajouter à celle qui tombe dans les vallées.

Deuxième cause: la pluie.

C'est un fait qui a été mis au jour par les observations météorologiques, que la pluie est en général plus abondante dans les lieux plus bas que dans les lieux plus élevés. Sans y mettre la précision que la science exige, il est peu de voyageurs habitués à courir les montagnes qui n'aient pas été témoins de ce fait. Souvent du sommet d'une montagne où l'on jouit d'un ciel pur et d'un soleil ardent, on entend sous ses pieds les roulements du tonnerre, et l'on voit les nuages s'étendre et se décharger sur les plaines. Cependant plusieurs fois les voyageurs ont été surpris

in these elevated regions. It is, therefore, also certain that rain falls there, which, infiltrating itself into the snow, freezes with it, and helps to convert it into ice.

Third Cause: Condensation of Vapours.

There certainly exists between the clouds and the tops of mountains an affinity which it is impossible not to recognize. Even when the sky is clear, the most elevated points are seen surrounded by mists more or less thick. If we watch above the valleys a cloud floating in the air, when it is not in a state of too great agitation, and follow it with the eye, we see it gradually direct itself towards the highest summit, cover it, envelop it, and, without passing beyond, dissipate itself and disappear at that spot. Mont Blanc, in particular, is nearly always hidden, and only now and then, so to speak, allows itself to be seen, and while the clouds in mid-air sail at the will of the winds, those that surround it seem to be chained there by an unknown force.

It is not uncommon, either, to see the cloud spring

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par des pluies dans ces hautes régions. Il est donc aussi constant qu'il y tombe de la pluie, qui s'infiltrant dans la neige, se congèle avec elle et contribue à la convertir en glace.

Troisième cause: condensation des vapeurs.

Il y a certainement entre les nuages et les cimes des montagnes une affinité qu'il est impossible de méconnaître. Alors même que le ciel est serein, on voit les pointes les plus élevées entourées de brouillards plus ou moins épais. Si l'on considère au-dessus des vallées un nuage flotter dans l'air quand l'agitation n'est pas trop grande, en le suivant de l'œil on le voit peu à peu se diriger vers la cime la plus haute, la couvrir, l'envelopper, et, sans passer outre, se dissiper, s'évanouir en cet endroit. Le Mont-Blanc surtout est presque continuellement caché et ne se laisse pour ainsi dire voir que par exception, et tandis que les nuages qui sont dans le milieu des airs voguent au gré des vents, ceux qui l'entourent y semblent enchaînés par une force inconnue.

Il n'est pas rare qu'on voie aussi le nuage naître et grandir

into being and grow about ice-clad ridges; it then seems to rest there like a cap to cover the summit; from time to time the wind tears from it a few shreds that sail in the air; but, generally speaking, this mist is eaten up on the spot. It is easy, as it seems to me, to follow the phases of its existence: the vapours, deprived of a great portion of their caloric by the neighbourhood of the glacier which absorbs it, take the vesicular form which renders them visible; the continued transmission of caloric makes them pass into the state of drops, and they fall upon the glacier. This fact is known to all persons who have been much of mountain wanderers. When we find ourselves suddenly enveloped by one of these mists, we see ourselves covered rapidly enough with moisture; the leaves of plants, the ground, the rocks are likewise wet as after a light rain. If we consider that the top of Mont Blanc is nearly always hidden by the mist which closely surrounds it, we are forced to give great importance to this means of growth.

All physicists are agreed in acknowledging that a considerable part of the moisture spread through the

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autour des crêtes glacées; alors il paraît rester là comme un bonnet pour couvrir la cime; de temps en temps le vent en arrache quelques flocons qui voguent dans les airs; mais pour l'ordinaire ce brouillard est dévoré sur place. Il est facile, ce me semble, de suivre les phases de son existence: les vapeurs privées d'une grande partie de leur calorique par le voisinage du glacier qui l'absorbe, prennent la forme vésiculaire qui les rend visibles, la transmission continue du calorique les fait passer à l'état de gouttes, et elles tombent sur le glacier. Ce fait est connu de toutes les personnes qui ont beaucoup parcouru les montagnes. Quand tout à coup on se trouve enveloppé d'un de ces brouillards, on se voit assez rapidement couvert d'humidité, les feuilles des plantes, le sol, les rochers sont eux-mêmes mouillés comme après une pluie légère. Si l'on considère que le sommet du Mont-Blanc est presque toujours caché par ce brouillard qui l'entoure de près, on est forcé de donner une très-grande importance à ce moyen d'accroissement.

Tous les physiciens sont d'accord pour reconnaître qu'une partie considérable de l'humidité répandue dans l'air rentre dans

air returns to the earth without having passed into the state of rain or snow. Vapours brought into contact with the rocks yield to them a portion of their caloric, are condensed, flow through the fissures, and go into internal reservoirs. This condensation of the vapours of the atmosphere is considered by many philosophers as the most fruitful source of the alimentation of springs. I shall show farther on that they are mistaken; still, they do but exaggerate the power of a phenomenon which is incontestable.

If it be true that vapours are condensed about rocks and on their summits when covered with vegetation, we shall easily understand that the condensing power of a mountain of ice must be much more considerable. In order to appreciate this excess, we should, as it seems to me, consider not only the difference of temperature, but also the difference of the heights and of the attractive masses that operate in producing condensation. But, to consider merely the general fact, we can understand that the frozen mass of Mont Blanc, isolated in the middle of the atmosphere, must produce there the effect of the condenser of a steam engine. It can be

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la terre sans avoir passé à l'état de pluie ni de neige. Les vapeurs mises en contact avec les rochers, leur cèdent une portion de leur calorique, se condensent, coulent à travers les fissures, et vont dans les réservoirs intérieurs. Cette condensation de vapeurs de l'atmosphère est considérée par beaucoup de savants comme la cause la plus féconde de l'alimentation de (*sic*) sources. Je montrerai plus tard qu'ils se trompent; mais ils ne font qu'exagérer la puissance d'un phénomène que est incontestable.

Si les vapeurs se condensent autour des rochers et sur leurs cimes couvertes de végétation, on comprendra facilement que la puissance condensatrice d'une montagne de glace doit être bien plus considérable. Pour apprécier cet excédant, il faudrait, ce me semble, non-seulement considérer la différence de température, mais encore la différence des hauteurs et des masses attractives agissant pour la condensation. Mais à ne considérer que la généralité du fait, on comprend que la masse glacée du Mont-Blanc isolée au milieu de l'atmosphère, doit y produire l'effet du condensateur des machines à vapeur. On peut établir

established, in principle, that every globule of vapour that touches it is immediately absorbed, and as the absorption of a globule creates a vacuum, it is instantly replaced by the globule which was behind, and so on. Or, if you will, abstracting the idea of atmospheric air, we may consider the mountain top as surrounded by a number of infinitely thin envelopes of moisture, and absorbing in succession those envelopes of vapour which are pressed against the surface of the glacier by the effect of the elastic force of the atmospheric fluids. This absorption, which must be continual, must yet be greater when the temperature of the air is higher.

These assertions as to the condensation of vapours are in perfect conformity with the results given by the hygrometrical experiments made by M. de Saussure on the summit of Mont Blanc. This philosopher found that at noon the air at the summit of Mont Blanc contained six times less humidity than at Geneva on the same day and at the same hour. Nearly the same proportion exists between Mont Blanc and Chamonix. Each cubic foot of air taken at the summit of the glaciers contained only one grain and seven-tenths of

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en principe que tout globule de vapeur qui la touche est immédiatement absorbé, et comme un globule absorbé fait un vide, il est aussitôt remplacé par le globule qui était derrière, et ainsi de suite. Ou, si l'on veut, en faisant abstraction de l'air atmosphérique, on peut considérer la cime de la montage comme entourée de diverses enveloppes humides infiniment minces, et absorbant successivement ces enveloppes de vapeurs qui se pressent contre la surface du glacier par l'effet de la tension des fluides atmosphériques. Cette absorption, qui doit être continuelle, doit pourtant être plus grande quand la température de l'air est plus élevée.

Ces assertions sur la condensation des vapeurs sont parfaitement conformes aux résultats donnés par les expériences d'hygrométrie faites par M. de Saussure au sommet du Mont-Blanc. Ce savant a trouvé qu'à midi l'air au sommet du Mont-Blanc contenait six fois moins d'humidité qu'à Genève au même jour et à la même heure. Cette même proportion à peu de difference près existe entre le Mont-Blanc et Chamonix. Chaque pied cube d'air pris au sommet des glaciers ne contenait qu'un

water in the form of vapour, whilst at Geneva it contained a little more than ten grains. We can only, as it seems to me, attribute this difference to the rapidity of the condensation.

There are a host of observations which, so to speak, render palpable the phenomenon of condensation. In the middle of summer a caraffe of fresh water is covered in a short time with a film of dew, of which the drops run together and flow down the sides of the vessel.

During winter, when the temperature exceeds six or seven degrees of cold, the windows of heated and inhabited rooms are covered during the night with a layer of ice, whose thickness sometimes exceeds the twelfth of an inch. This is on a small scale what takes place on a great scale upon the glaciers.

The inhabitants of the high Alps of Switzerland have remarked that the movements of glaciers such as avalanches, falls of ice-blocks, opening of cracks, are more frequent in moist weather, on the approach of rain; the reason being that, as the condensation is then more considerable, the ice receives an increment which

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grain sept dixièmes d'eau réduite en vapeur, tandis qu'à Genève il en contenait un peu plus de dix grains. On ne peut, ce me semble, attribuer cette différence qu'à la rapidité de la condensation.

Il y a une foule d'observations qui rendent pour ainsi dire palpable le phénomène de la condensation. Au milieu de l'été, une caraffe d'eau fraîche se couvre en peu de temps d'une couche de rosée dont les gouttes se rassemblent et coulent le long des parois du vase.

Pendant l'hiver, quand la température dépasse six ou sept degrés de froid, les vitres des appartements chauffés et habités se couvrent pendant la nuit d'une couche de glace dont l'épaisseur dépasse quelquefois une ligne. C'est, en petit, ce qui se produit en grand sur les glaciers.

Les habitants des hautes Alpes de la Suisse ont remarqué que les mouvements des glaciers, comme les avalanches, les chutes, les fentes, sont plus fréquents dans les temps humides, aux approches des pluies; la raison en est que la condensation étant alors plus considérable, les glaces reçoivent un accroisse-

over-loads it, and destroys the equilibrium which existed between their weight and their cohesion.

These considerations might perhaps furnish the explanation of a phenomenon which is observed in all the high valleys of the Alps. It is this: In passing through the Vallée de Maurienne (which I select to quote, because it was there that I first observed the phenomenon in question) we see that all the trees at the bottom of the valley are inclined towards the upper end of the same valley; a circumstance which forces us to conclude that the winds blow chiefly in that direction. In fact, those who inhabit these valleys know that, from the first days of April to near the end of September, every day towards nine o'clock in the morning, a wind rises which blows up the valley, and which, after having acquired the maximum of its intensity towards two or three o'clock, ends with the day. It is felt only in the valley, and those who are at the top of the mountains do but see its effects from a distance. This astonishing periodicity strongly excited my curiosity. I sought for the solution of the problem; I give here that which has appeared to me the most plausible, without how-

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ment qui les surcharge et rompt l'équilibre qui existait entre leur pesanteur et leur solidité.

Ces considérations pourraient peut-être fournir l'explication d'un phénomène qui se manifeste dans toutes les hautes vallées des Alpes. Le voici: en parcourant la vallée de Maurienne, que je cite de préférence parce que c'est là que j'ai pour la première fois observé le phénomène dont il s'agit, on voit que tous les arbres du fond de la vallée sont inclinés vers le haut de cette même vallée, ce qui oblige de suite à conclure que les vents soufflent plus ordinairement dans cette direction. En effet, ceux qui habitent ces vallées savent que, depuis les premiers jours d'avril jusque vers la fin de septembre, tous les jours vers les neuf heures du matin on sent s'élever un vent qui remonte, et qui après avoir acquis le maximum de son intensité vers les deux ou trois heures, finit avec le jour. Il ne se fait sentir que dans la vallée, et ceux qui sont au sommet des montagnes n'en voient les effets que de loin. Cette étonnante périodicité a vivement piqué ma curiosité. J'ai cherché la solution du problême; je donne ici celle qui m'a paru la plus

ever placing entire faith in it. When dealing with the investigation of the causes which produce the phenomena of nature, I mistrust my own theories as much as those of others. I give the idea that has suggested itself to me; if it be untenable, I shall with pleasure see justice executed upon it.

It is in the middle of the day that evaporation, being favoured by the increase of temperature, is most considerable. It is also in the middle of the day that the difference of temperature between the glaciers and the vapours of the atmosphere is most considerable. If then there be at the summit of the chain of the Alps a great absorption of vapour in the neighbourhood of the snows, ice, and granite peaks, is it not natural that the vacuum produced in the mid-region of the atmosphere should be filled up by the vapours which continue to be formed at the bottom of the valleys, and that a current should be thus established whose direction would be towards the upper end of the valley?

Moreover, the hygrometrical observations of M. de Saussure have proved that, *cæteris paribus*, the quantity of vapour held in suspension in the air becomes less on these heights, and the reasons which may be

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plausible, sans cependant y ajouter une entière foi. Quand il s'agit de la recherche des causes productrices des phénomènes de la nature, je me défie autant de mes propres systèmes que de ceux des autres. Je donne la pensée qui m'est venue; si elle est fausse, je verrai avec plaisir qu'on en fasse justice.

C'est au milieu du jour que, favorisée par l'élévation de la température, la vaporisation est plus considérable; c'est aussi au milieu du jour que la différence de température entre les glaciers et les vapeurs de l'air se trouve plus considérable. Si donc il y a au sommet de la chaîne des Alpes une grande absorption de vapeur autour des neiges, des glaces et des aiguilles granitiques, n'est-il pas naturel que le vide produit dans la partie moyenne de l'atmosphère soit comblé par les vapeurs qui continuent à se former au fond des vallées, et qu'il s'établisse ainsi un courant dont la direction serait vers le haut des vallées?

D'ailleurs les observations hygrométriques de M. de Saussure ont prouvé que, toutes choses égales, la quantité de vapeur tenue en dissolution dans l'air devient moindre sur ces hauteurs, et

given for such a phenomenon are that, there, evaporation is almost nothing, whilst absorption must be very great; it is therefore not surprising that the quantity which remains in the atmosphere should be less than what there is in the lower portion of the valleys.

Lastly, it is also a recognized fact that during the day the formation of vapours gives rise to a wind ascending vertically, and that during the night the vapours in course of condensation must fall and give rise to a contrary movement, except of course in the high valleys, where the vapours do not return, because they have been absorbed on the cold summits. But this movement of air, which in the plains is purely vertical, must follow the slope of the valleys in which the condensation is effected. I might develop this subject further, but I think I have said enough to put the reader on the track. I shall conclude by quoting an observation of M. de Saussure, which tends to confirm my theory.

"On approaching the plain of the Mont Cenis . . "I observed a meteorological phenomenon of great "interest by reason of the conclusions that may be

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les raisons que l'on peut en donner sont que la vaporisation y est presque nulle, tandis que l'absorption doit y être très-grande; il n'est donc pas étonnant que la quantité qui reste dans l'atmosphère soit moindre que celle qui est au bas de vallées.

Enfin, c'est encore une chose reconnue que, pendant le jour, la formation des vapeurs donne lieu à un vent vertical ascensionnel, et que, pendant la nuit, les vapeurs en voie de condensation doivent s'abaisser et donner lieu à un mouvement contraire; excepté pourtant dans les hautes vallées, où les vapeurs n'ont pas de retour, puisqu'elles ont été absorbées sur les cimes froides. Mais ce mouvement d'air, qui est purement vertical dans les plaines, doit suivre la pente des vallées où la condensation s'opère. Je pourrais donner à ce sujet d'autres développements, mais je crois en avoir dit assez pour mettre sur la voie. Je terminerai en citant une observation de M. de Saussure, qui tend à confirmer ma théorie:

"En approchant la plaine du Mont-Cenis.....j'observai un "phénomène météorologique bien intéressant par les inductions

"drawn from it. The valley of the Mont Cenis is "open to the north-west on the Savoy side, and to the "south-east on the Piedmont side, whilst on the north-"east and south-west it is bounded by high mountains. "Towards the evening, the valleys, as well on the side "of Piedmont as on that of Savoy, were filled with "clouds, and by a very remarkable chance the wind "was blowing in opposite directions in Savoy and Pied-"mont. Thus the meeting place of these winds was "in the valley of the Mont Cenis, and the clouds were "seen entering this valley by its two opposite extremi-"ties. One would suppose, therefore, that it must "soon have been filled with clouds; but not at all; no "sooner did they enter, whether on one side or on the "other, than they melted in the air and disappeared "altogether; so that, in spite of the quantity of clouds "which ceased not to pour into the valley, the air "remained ever clear and transparent." (*Voyages dans les Alpes*, tom. 3.)

During the night the wind changes and descends from the heights towards the lower parts, but it is feeble, and scarcely makes itself felt except upon the smoke which it carries away. The quantity of air which

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"que l'on peut en tirer. La vallée du Mont-Cenis est ouverte "au nord-ouest du côté de la Savoie, et au sud-est du côté du "Piémont, tandis qu'au nord-est et au sud-est (*sic*) elle est bordée "de hautes montagnes. Sur le soir, les vallées, tant du côté du "Piémont que du côté de la Savoie, étaient remplies de nuages, "et par un hasard assez extraordinaire, il soufflait des vents "opposés en Savoie et en Piémont. Ainsi le rendezvous de ces "vents était dans la vallée du Mont-Cenis, et l'on voyait des "nuages entrer dans cette vallée par ses deux extrémités "opposées. On croirait donc qu'elle aurait du être bientôt "remplie de nuages, et point du tout; à mesure qu'ils y entraient, "soit d'un côté, soit de l'autre, ils se fondaient dans l'air et "disparaissaient entièrement; en sorte que malgré la quantité "de nuages qui ne cessaient d'y entrer, l'air y demeurait toujours "clair et transparent." (*Voyage dans les Alpes*, tom. 3.)

Pendant la nuit le vent change et descend des hauteurs vers le bas, mais il est faible et n'est guère sensible que sur la fumée qu'il emporte. La quantité d'air qui revient dans la plaine est

returns to the plain is due, I think, only to the condensation of the atmospheric air. This condensation must be especially considerable in low places, because the difference of temperature between the middle of the day and the middle of the night is greater here than in elevated places, where it is scarcely perceptible. Thus, during the day two causes contribute to produce the ascending wind—evaporation and expansion; or, if you will, two quantities of fluid rise—the vapour produced and the expanded air; hence the wind is strong and rapid. But in the evening, the vapour having been absorbed, one quantity alone returns—viz., the condensed air; and hence the wind is feebler.

More than a year had elapsed since I had written this passage, on a meteorological phenomenon of the valleys, which has always appeared to me as interesting to study as it is difficult to explain, when the paper of M. Fournet, Professor in the Faculty of Sciences of Lyons, appeared. The learned professor has made a complete study of *the day and night breezes around mountains*. The fact of the diurnal ascending winds is perfectly established in his work.

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due, je pense, à la seule condensation de l'air atmosphérique. Cette condensation doit être surtout considérable dans les lieux bas, parce que la différence de température entre le milieu du jour et le milieu de la nuit est plus grande sur ce point que dans les lieux élevés, où elle est à peine sensible. Ainsi, pendant le jour, deux causes contribuent à produire le vent ascensionnel: la vaporisation et la dilatation, ou, si l'on veut, deux quantités de fluides s'élèvent: la vapeur produite et l'air dilaté; dès lors le vent est fort et rapide. Mais le soir, la vapeur ayant été absorbée, une seule quantité revient, à savoir: l'air condensé; et dès lors le vent est plus faible.

Il y avait plus d'une année que j'avais écrit ce passage sur un phénomène météorologique des vallées, qui m'a toujours paru aussi intéressant à étudier que difficile à expliquer, quand a paru le Mémoire de M. Fournet, professeur à la faculté des sciences de Lyon. Le savant professeur a fait une étude complète des *brises de jour et de nuit autour des montagnes*. Le fait des vents ascendants diurnes est parfaitement établi dans son ouvrage. Peut-être y aurait-il quelque chose de plus à

Perhaps there may be something left to desire as to the evening breeze, which is not so well known with respect to the hours at which it commences, at which it acquires its greatest force, and at which it ceases to be perceptible; its intensity relatively to that of the day breeze is not sufficiently appreciated, either; but all the circumstances of atmospheric pressure, of temperature, and of hygrometry that accompany the phenomenon have been examined by M. Fournet with as much precision as it is possible to bring to bear upon the examination of a question which has been submitted but quite lately to the attention of men of science.

In his theoretical discussion, M. Fournet applies to the present case the principles enunciated in the *Physique du Globe* of M. Saigey. His explanation is summed up in the following axiom, which is taken from the author just cited—"Whenever the air is heated, it flows from "low places towards high places; and it cannot cool "without flowing in part from high places toward low "places." So that, in the cause he assigns for the ascending wind of mountain regions, M. Fournet takes into account only the expansion of atmospheric air

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désirer relativement à la brise du soir, qui n'est pas aussi bien connue quant aux heures où elle commence, où elle a acquis sa plus grande force, et où elle cesse d'être sensible; son intensité relative à celle du vent diurne n'est pas non plus suffisamment appréciée; mais toutes les circonstances de pression atmosphérique, de température et d'hygrométrie qui accompagnent le phénomène, ont été examinées par M. Fournet, avec autant de précision qu'il est possible d'en mettre dans l'examen d'une question qui n'est soumise que depuis peu de temps à l'attention des physiciens.

Dans sa discussion théorique, M. Fournet applique au cas présent les principes énoncés dans la *Physique du globe* de M. Saigey. Son explication se résume dans l'axiome suivant, qui est encore de l'auteur que nous venons de citer: "Toutes les "fois que l'air se réchauffe, il afflue des lieux bas vers les lieux "élevés; et il ne peut se refroidir, sans couler en partie des "lieux élevés vers les lieux bas." De sorte que M. Fournet ne fait entrer que la dilatation de l'air atmosphérique par l'élévation

by reason of increase of temperature. In spite of the regard I entertain for the opinion of so distinguished a philosopher, I hold to the belief that the condensation of vapour on cold and icy summits must enter as a principal element into the theory of the day and night breezes of high valleys.

In fine, combining the three causes that contribute to the maintenance of reservoir glaciers, it would be interesting to determine the mass that is supplied to them each year. But one feels that it is impossible to have on this subject anything but conjectures more or less probable; it is here especially that we want, and always shall want, observations, which must be the first element to bring to a comprehension of nature. We know, however, that the days are very few when the summit of Mont Blanc is laden with neither snow, nor rain, nor mist. Those who wish to undertake the ascent are often forced to wait long before they find a favourable day, and they are even often forced to retrace their steps on account of storms.

Again, we know that the formation of ice is rapid on

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de la température, dans la cause qu'il assigne au vent ascensionnel des montagnes. Malgré la considération que je professe pour l'opinion d'un savant aussi distingué, je persiste à croire que la condensation des vapeurs au sommités froides et glacées doit entrer comme élément principal dans la théorie des brises de jour et de nuit des hautes vallées.

Enfin, combinant entre elles les trois causes qui contribuent à l'entretien des glaciers-réservoirs, il serait intéressant d'arriver à la masse qui leur est fournie chaque année; mais on sent qu'il n'est possible d'avoir sur ce sujet que des conjectures plus ou moins vraisemblables; c'est surtout ici que nous manquons et que nous manquerons toujours des observations qui doivent être le premier élément pour mener à l'intelligence de la nature. Cependant nous savons que les jours où la neige, la pluie ou les brouillards ne chargent pas le sommet du Mont-Blanc sont très-rares dans l'année; ceux qui veulent entreprendre de le visiter sont souvent forcés d'attendre long-temps avant de trouver un jour propice, et souvent même ils sont forcés de rebrousser chemin à cause des orages.

Nous savons encore que la formation des glaces est rapide

these heights. M. de Saussure could not find, on descending, the track which he had made the evening before.

In the end of August, 1837, there were two ascents which succeeded perfectly; the first party, which was numerous, had traced on the snow and on the ice a path which could be followed by the eye from the village of Chamonix; they had cut an ascent of 80 steps in the living ice, and for all that, the second party, who passed in the same place two days afterwards, could find no trace of path or steps. There had been neither rain nor snow; everything had been effaced by the wind and the condensation of vapour. These same facts having been observed several times by other travellers, we may conclude that the effects of condensation are considerable.

Taking as our starting point what happens elsewhere, we may, I think, without exaggeration suppose, first, that the layer of vapour condensed each day amounts to the thickness of the twelfth of an inch, which would give an increment, from vapour, of 30 inches a year; but, to be under the mark, let us reduce this amount to one-half. Secondly, supposing that at the

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sur ces hauteurs. M. de Saussure ne trouvait plus, en redescendant, le chemin qu'il avait tracé la veille.

A la fin d'août 1837, il y a eu deux ascensions qui ont parfaitement réussi; la première caravane, qui était nombreuse, avait tracé sur la neige et sur la glace un chemin que l'on pouvait suivre de l'œil depuis le bourg de Chamonix; elle avait taillé un escalier de 80 marches dans la glace vive, et pourtant la seconde caravane qui passa dans le même endroit, deux jours après, ne trouva plus aucune trace de chemin ni d'escalier. Il n'y avait eu ni pluie ni neige, tout avait été effacé par le vent et la condensation des vapeurs. Ces mêmes faits ayant été plusieurs fois observés par d'autres voyageurs, on peut en conclure que les effets de la condensation sont considérables.

En prenant pour point de départ ce qui se passe ailleurs, on peut, ce me semble, sans exagération, supposer, 1° que la couche de vapeur condensée chaque jour s'élève à une ligne d'épaisseur, ce qui donnerait par la vapeur un accroissement de 30 pouces par année; mais pour rester plutôt en dessous, réduisons cette somme à moitié; 2° en supposant qu'au sommet du Mont-Blanc

summit of Mont Blanc the quantity of snow which falls in one year is less than in the valleys which surround it, I think that there is no exaggeration in placing the quantity at 100 inches. Thirdly, the mean rainfall upon plains within the tropics is about 20 inches: but at the foot of the Alps, in the high valleys, this mean rises considerably, and may be estimated, I think, at 23 or 24 inches. The observations of M. Mottard, made at Saint Jean de Maurienne, put it at 25 inches and two-tenths for 1836; those of the Abbé Chamousset put it at about 29 inches for the year 1839. But, as it is to be presumed that rain is less abundant at great heights, we may reduce this quantity by more than one-half, and fix it at 12 inches.

Before deducing the total increment which Mont Blanc must receive every year, there are several remarks to be made—the first is, that the three elements of which we have just spoken are reduced to ice, and consequently change their volume. Water and condensed vapour are augmented by one-fourteenth of their volume on reaching congelation, and snow loses

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la quantité de neige qui tombe dans une année est moindre que dans les vallées qui l'entourent, je pense qu'il n'y a pas d'exagération à porter cette quantité à 100 pouces; 3° la moyenne des pluies dans les plaines intertropicales est d'environ vingt pouces; mais au pied des Alpes, dans les hautes vallées, cette moyenne s'élève considérablement, et peut se porter, je pense, de 23 à 24 pouces. Les observations de M. Mottard, faites à Saint-Jean-de-Maurienne, portent 25 pouces 2/10 pour 1836; celles de M. l'abbé Chamousset la portent à 29 pouces environ pour l'année 1839. Cependant, comme il est à présumer que la pluie est moins abondante sur les grandes hauteurs, nous pouvons réduire cette quantité de plus de moitié, et porter 12 pouces de pluie.

Avant de déduire le total d'accroissement que le Mont-Blanc doit recevoir chaque année, il y a plusieurs observations à faire: la première est que les trois éléments dont nous venons de parler se réduisent en glace, et par conséquent changent de volume; l'eau et la vapeur condensée augmentent d'un 14e de leur volume en arrivant à la congélation, et la neige en perd

much more in its conversion to the state of ice. The ice, however, which results from this last formation is not a compact and pure ice like that formed on the surface of a lake: it is mixed with everything that the winds incessantly carry on to its surface; it is bubbly, filled with small globules of air. When, in crevasses in which we can look at the profile of a glacier, we see different beds distinct in colour, but above all in density, some seem to have the hardness and greenish colour of ice, and others preserve the whiteness and porosity of snow. There are in the mass both large and small layers. Each of the first, no doubt, represents a year, and each of the second represents, perhaps, a season, a day of rain, a fall of snow, a period of violent sun-heat. If we compare in weight two cubes of ice of equal dimensions, the one of compact ice, and the other of ice containing air bubbles, the first will weigh about one-quarter more than the second. It seems to me, therefore, that the 15 inches of vapour, and the 12 inches of rain, will give about 33 inches of aërated ice. We must add to this the result of snow.

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beaucoup plus pour arriver à l'état de glace. Cependant la glace qui résulte de cette dernière formation n'est pas une glace compacte et pure comme celle qui se forme à la surface d'un lac; elle est mélangée de tout ce que les vents apportent sans cesse à la surface; elle est bulleuse, remplie de petits globules d'air. Quand, dans les crevasses où l'on peut apercevoir le profil d'un glacier, on voit différentes couches distinctes par la couleur, mais surtout par la densité, quelques-unes semblent avoir toute la dureté et la couleur verdâtre de la glace, et d'autres conservent la blancheur et la porosité de la neige. Il y a dans l'ensemble de grandes et de petites assises. Les premières représentent sans doute les années, et les secondes représentent peut-être une saison, un jour de pluie, une chute de neige, un violent coup de soleil. Si l'on compare par le poids deux cubes de glace d'égales dimensions, l'un de glace compacte et l'autre de glace bulleuse, le premier pésera un quart environ plus que le second. Il me paraît donc que les 15 pouces de vapeur et les 12 pouces de pluie peuvent donner en glace bulleuse environ 33 pouces. Il faut ajouter à cela le résultat de la neige.

I have put the snow of one year at 100 inches; we ought to know by how much this volume will be reduced in passing to the state of ice. To arrive at this, I made some experiments, and found that snow which had fallen within a week, and in weather which had never ceased to be below the freezing point, only gave one-eighth of its volume when reduced to water, and that this quantity increased in proportion as the snow became harder, by being subjected to a higher temperature. I found some which gave one-third of its volume when reduced to water; but since, at the summit of Mont Blanc, the temperature is below the freezing point, we shall take the first experiment as our starting point, and shall have 100 inches of snow yielding about 12 inches of water, which in their turn will give us about 15 inches of ice containing air bubbles, and we shall have for the total increment 15 + 33 = 48 inches of ice, which will come to be added every year to the mass of the reservoir glacier.

It must be apparent that in most of these calculations I may for want of exact observation be either above or below the truth; but I have sought rather to

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J'ai porté à 100 pouces la neige d'une année; il faudrait savoir de combien ce volume se réduirait en passant à l'état de glace. Pour y parvenir j'ai fait quelques expériences, et j'ai trouvé que la neige tombée depuis huit jours par un temps qui n'avait pas cessé d'être au-dessous de zéro, ne donnait, réduite en eau, qu'un 8e de son volume, et que cette quantité s'élevait à mesure que la neige devenait plus dure en étant soumise à une température plus élevée. J'en ai trouvé qui a donné, réduite en eau un tiers de son volume; mais comme au sommet du, Mont-Blanc la température est au-dessous de zéro, nous partirons de la première expérience, et nous aurons 100 pouces de neige fournissant environ 12 pouces d'eau, qui à leur tour nous donneront environ 15 pouces de glace bulleuse, et nous aurons pour accroissement total 15 p^{ces} × 33 p^{ces} = 58 pouces de glace (*sic*), qui viendrait chaque année s'ajouter à la masse du glacier-réservoir.

On sent que dans la plupart de ces évaluations j'ai pu, manquant d'observations précises, me placer en dessus ou en dessous de la vérité; mais j'ai plutôt cherché à rester en

keep below it. If then the reservoir glaciers lost nothing of what they receive, we should see them rise in the air until they had passed beyond the regions accessible to aqueous vapour. Mont Blanc in particular would rise more than 400 feet in a century, and more than 4,000 feet in a thousand years. Now it is quite evident that nothing of the kind takes place in nature.

The economy of the world would soon be destroyed if at certain particular points there could be accumulations of matter. The centre of gravity of the globe would be insensibly displaced, and perturbation would take the place of the admirable regularity of its movements. If the poles did not return to the equatorial seas the waters which, in the form of vapour, take their departure day by day from those burning regions to go and be converted into ice at the two extremities of the earth, the ocean would be exhausted, and life would cease with water to circulate in the world. The conservative will of the Creator has used for the permanance of His work the vast and powerful law of *circulation*, which, when examined closely, is found to be reproduced in all parts of nature. Water circulates from

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dessous. Si donc les glaciers-réservoirs ne perdaient rien de ce qu'ils reçoivent, on les verrait s'élever dans les airs jusqu'à ce qu'ils eussent dépassé la région accessible aux météores aqueux. Le Mont-Blanc en particulier s'élèverait de plus de 400 pieds par siècle et de 4,000 pieds dans mille ans. Or, il est bien évident que rien de semblable n'a lieu dans la nature.

L'économie du monde serait bientôt détruite, s'il pouvait y avoir sur certains points particuliers des accumulations de matière. Le centre de gravité du globe se trouverait insensiblement déplacé, et la perturbation succèderait à l'admirable régularité des mouvements. Si les pôles ne renvoyaient pas aux mers équatoriales les eaux qui, réduites en vapeur, partent chaque jour de ces régions brûlantes pour aller se convertir en glace aux deux extrémités de la terre, l'Océan s'épuiserait et la vie cesserait avec l'eau de circuler dans le monde. La volonté conservatrice du Créateur a employé pour la permanence de son ouvrage la vaste et puissante loi de la *circulation*, qui, examinée de près, se trouve reproduite dans toutes les parties de la nature. L'eau circule de l'Océan dans les airs, des airs sur

the ocean into the air, from the air on to the land, and from the land into the seas—"The rivers return from whence they came forth, that they may flow anew," says the Holy Spirit (*Eccles.* ix. 1, 7); the air circulates round the globe, and, so to say, upon itself, in passing and repassing successively through all the heights of the atmospheric column. The elements of organic substance circulate in passing from the solid to the liquid or gaseous state, and from that to the state of solidity and organization. That universal agent which we designate by the name of heat, light, electricity, and magnetism, has probably also a round of *circulation* as extended as the universe. If some day its movement should be better known to us, it is probable that it will give us the solution of a host of problems which still weigh upon the human mind. Carried into every part of the whole, circulation is still the law of life, the mode of action employed by Providence in the administration of the universe. In the insect, as in the plant and as in the human body, there is a circulation, or rather several circulations, of blood, of humours, of elements, of fire, and of all that enters into the composition of the individual.

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la terre, et de la terre dans les mers; "Les rivières retournent "d'où elles sont sorties, afin qu'elles coulent de nouveau," dit l'Esprit saint. *Eccles.* 9, 1, 7; l'air circule autour du globe et pour ainsi dire sur lui-même, en passant et repassant successivement par toutes les hauteurs de la colonne atmosphérique. Les éléments de la substance organique circulent en passant de l'état solide à l'état liquide ou aériforme, et de celui-ci à l'état de solidité et d'organisation. Cet agent universel que nous désignons sous les noms de feu, de lumière, d'électricité et de magnétisme, a probablement aussi un cercle de *circulation* aussi étendu que l'univers. Si quelque jour son mouvement pouvait nous être mieux connu, il est probable qu'il nous donnerait la solution d'une foule de problèmes qui pèsent encore sur l'esprit humain. Ramenée dans chaque partie du tout, la circulation est encore la loi de vie, le mode d'action employé par la providence dans l'administration de l'univers. Dans l'insecte comme dans la plante et comme dans le corps humain, il y a une circulation, ou plutôt plusieurs circulations de sang, d'humeurs, d'éléments, de feu et de tout ce qui entre dans la composition de l'individu.

And we ourselves—spirit, intellect, and will—do not we also obey the universal law of circulation in returning by the path of humanity into the very bosom of God, from whence we sprung? Should it be thought that I am wandering from my subject, I would answer that it is impossible that a profound study of nature should fail to lead us back to God.

"It must not then be believed," says M. de Saussure,* "as some persons have supposed, that the thickness of "the ice is continually increasing. Here, as in so many "other cases, the causes of increment find limits at "which the causes of destruction overpower them, and "at which nature has fixed for herself boundaries which "she never oversteps."

M. de Saussure tried to ascertain the thickness of ice which covers the summit of the colossus of the Alps. In several places where this thickness is visible on the flanks of rocks, he measured it, and found only cuttings of from 12 to 50 feet. His opinion is that nowhere does it exceed 200 feet. In fact we see in

* *Voyage dans les Alpes*, tome 4, p. 204.

Et nous-mêmes, esprits, intelligences et volontés, n'obéissons-nous pas aussi à la loi universelle de la circulation, en retournant par la voie humanitaire jusque dans le sein de Dieu d'où nous sommes sortis! Si l'on trouvait que je m'écarte de mon sujet, je répondrais qu'il est impossible que l'étude approfondie de la nature ne ramène pas à Dieu.

"Il ne faut donc pas croire, dit M. de Saussure,* comme "l'ont supposé quelques personnes, que l'épaisseur des glaces "augmente continuellement. Ici, comme en tant d'autres "occurrences, les causes d'accroissement trouvent des limites "où les causes de destruction les atteignent, et où la nature "s'est fixée à elle-même des bornes qu'elle ne dépasse jamais."

M. de Saussure a cherché à connaître quelle pouvait être l'épaisseur de glace qui recouvre la cime du colosse des Alpes. Dans plusieurs endroits où cette épaisseur est visible sur le flanc des rochers, il l'a mesurée et n'a trouvé que des tranches de 12 à 50 pieds; son opinion est que nulle part elle ne dépasse deux cents pieds. En effet, on voit dans plusieurs endroits au-

* *Voyage dans les Alpes*, tome 4, p. 204.

several places below the summit rocks belonging to the kernel of the mountain jutting out as *aiguilles* above the surface of the snow; a circumstance which sufficiently proves that its increase is not unlimited, and that its mass is always very nearly the same.

CHAPTER IV.

OF THE CAUSES OF DIMINUTION IN RESERVOIR GLACIERS.

In pointing out the causes of decrease in the higher glaciers, M. de Saussure reckons three only—viz., melting, whether of the bottom or of the surface, evaporation, and winds.* It is very surprising that the learned explorer of the Alps, who points out in several passages of his *Mémoires* the true system of the formation of the lower glaciers, appears in this and in some other places not to have very just notions as to the unity which

* *Voyage dans les Alpes*, tom. 4, p. 204.

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dessous de la cime, les rochers appartenant au noyau de la montagne, dépasser en aiguilles la surface des neiges, ce qui indique assez que leur accroissement n'est pas indéfini et que leur masse est toujours à très-peu près la même.

CHAPITRE IV.

DES CAUSES DE DIMINUTION DES GLACIERS-RÉSERVOIRS.

En indiquant les causes de diminution des glaciers supérieurs, M. de Saussure n'en compte que trois, savoir: la fonte soit du fond soit de la surface, l'évaporation et les vents.* Il est bien étonnant que le savant explorateur des Alpes qui indique dans plusieurs passages de ses Mémoires le véritable système de la formation des glaciers inférieurs, paraisse dans celui-ci et dans quelques autres ne pas avoir une idée bien juste sur cet ensemble qui

* *Voyage dans les Alpes*, tome 4, pag. 204.

binds in one reservoir glaciers and stream glaciers. There is no doubt that if this scrupulous observer of the phenomena of mountains had occupied himself specially with glaciers, as he has done with rocks and meteorology, he would have understood that the causes of diminution which he points out are too small compared with the causes of increase to account for the sort of immutability which characterizes the higher glaciers. In truth, the fact of melting underneath the glaciers is almost a gratuitous assumption, not even proved by the flow of water, which begins only in regions far below the reservoir glaciers. Granting central heat to be a fact —a doctrine not yet admitted by all men of science, and from which a recoil has begun as from an assertion of which the proofs are not incontestable—we shall understand that the effect of this heat, which even at the level of the sea is scarcely appreciable, must be much less so at the summit of a granite peak which rises to 14,000 [French] feet above that level. Even at a spot where this heat, not central, but subterranean, exists in a manner that admits of no doubt, and at a high degree of temperature, its influence on the melting of the snow,

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lie les glaciers-réservoirs aux glaciers (*sic*) d'écoulement. Il n'est pas douteux que si cet observateur scrupuleux des phénomènes des montagnes se fût occupé d'une manière spéciale des glaciers comme il l'a fait pour les roches ou la météorologie, il aurait compris que les causes de diminution qu'il indique sont trop inférieures aux causes d'accroissement pour rendre raison de l'espèce d'immutabilité des glaciers supérieurs. En effet, la fonte au fond des glaciers est une supposition à très-peu près gratuite, qui n'est pas même démontrée par l'écoulement des eaux, qui ne commence que dans les régions bien inférieures aux glaciers-réservoirs. En admettant comme un fait la chaleur centrale, qui n'est pas encore un dogme démontré pour tous les physiciens, et dont on commence à revenir comme d'une assertion dont les preuves ne sont pas irrécusables, on comprendra que l'effet de ce feu déjà si peu sensible au niveau de la mer, doit l'être bien moins au sommet d'une pointe granitique qui s'élève à 14 mille pieds au-dessus. Là même où cette chaleur, non pas centrale, mais souterraine, existe d'une manière incontestable et à un haut degré de température,

is scarcely sensible. At a height of 9,000 [French feet Mount Etna is surrounded with a girdle of snow, which never completely melts: *à fortiori*, would it be the same with a mountain of the same height, situated beneath the same parallel, and deprived of the subterranean fires which never cease in the interior of Etna. On the 24th May, 1834, M. de Tilly, who penetrated into the great crater of this volcano, found there a bank of snow which had hitherto resisted the internal heat as well as the volcanic smoke with which it was nearly always surrounded.* The action of central heat is constant and uniform in the same place, as has been proved by the experiments made in the cellars of the Observatory of Paris. If, then, this action, independent of the atmospheric temperature, were at work constantly on the interior surface of the glaciers, there would be during winter a continuous melting, which might be estimated by the quantity of water issuing from beneath the glacier. Now this quantity is scarcely sufficient

* *Ascension aux Cimes de l'Etna et du Mont-Blanc*, par M. le Comte Henri de Tilly, p. 27.

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son action est peu sensible sur la fonte des neiges. A la hauteur de 9 mille pieds, le Mont-Etna est entouré d'une ceinture de neige qui ne fond jamais entièrement; à plus forte raison en serait-il de même d'une montagne de la même élévation et placée sous le même parallèle, et qui serait dépourvue des feux souterrains qui ne cessent jamais dans l'intérieur de l'Etna. Au 24 mai 1834, M. de Tilly, qui pénétra dans le grand cratère de ce volcan, y trouva un banc de neige qui avait jusque-là résisté à la chaleur interne aussi bien qu'à la fumée volcanique dont il était presque toujours entouré *. L'action de la chaleur centrale est constante et uniforme dans le même lieu, comme l'ont prouvé les expériences faites dans les caves de l'Observatoire de Paris. Si donc cette action indépendante de la température atmosphérique agissait constamment sur la surface intérieure des glaciers, il y aurait pendant l'hiver une fusion continue que l'on pourrait apprécier par la quantité d'eau qui sortirait de dessous le glacier. Or, cette quantité est à peine suffisante

* *Ascension aux cimes de l'Etna et du Mont-Blanc* par M. le comte Henri de Tilly, page 27.

to represent the water of the springs which must naturally flow in the bottom of the glacier valley, and which must bear some proportion to the considerable extent of ground which it occupies, and to the height of the mountains which surround it.

Lastly, there is a phenomenon which more than any other demonstrates the powerlessness, or at least the insufficiency, of internal heat to effect the melting of the ice. There are in different regions subterranean glaciers which remain perpetually motionless, and in which we perceive no trace of melting. Such are those found in the Bauges, in the neighbourhood of Chambéry. Winter restores to this natural ice-house what is taken from it during the summer, but the melting is *nil* in the lower parts. This fact is against the action of central heat in melting glaciers. As at present advised, therefore, I regard this melting as *nil*. There remains the melting at the surface of the glacier, which appears to me still more absolutely *nil;* and here, there is a manifest contradiction between the assertion of M. de Saussure and all his experiments. They were made in weather best suited for the purpose, the hottest

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pour représenter l'eau des sources qui doivent naturellement couler dans le fond de la vallée du glacier, et qui doivent répondre à l'étendue considérable du terrain qu'il occupe et à la hauteur des montagnes qui l'entourent.

Enfin, il est un phénomène qui démontre plus que tous les autres la nullité ou au moins l'insuffisance de la chaleur centrale pour opérer la fusion des glaces. Il y a dans différentes régions des glaciers souterrains qui demeurent dans une perpétuelle immobilité, pour lesquels on n'aperçoit aucune trace de fusion. Tels sont ceux qui se trouvent dans les Bauges, aux environs de Chambéry. L'hiver rend à cette glacière naturelle ce qu'on lui enlève pendant l'été ; mais la fusion est nulle dans les parties inférieures. Ce fait ne prouve pas en faveur de l'action de la chaleur sur la fusion des glaciers. Jusqu'à plus ample informé, je regarde donc cette fusion comme nulle. Reste la fusion à la surface des glaciers, qui me paraît plus nulle encore ; et ici il y a contradiction évidente entre l'assertion de M. de Saussure et toutes ses expériences. Elles ont été faites dans le temps le mieux choisi, le plus chaud de l'année, dans les heures où la

in the year, at the hours at which the temperature reaches its maximum, and the result was not even in any one instance in favour of melting. The thermometer always remained below the freezing point.

During a stay of more than fifteen days made in the month of July, on the Col du Géant, at a station only 10,578 [French] feet above the level of the sea, he found that it froze—there was either snow or hail—every evening; and the temperature of this half of July was very nearly that of the month of January in Geneva; from which we may conclude, as it seems to me, that at greater heights melting is not only insensible, but absolutely nothing. Nor is this all: observations made in the same place have proved that there was still congelation on the very surface of the snow when the thermometer stood at over 34° (Fahrenheit) in the atmospheric air. He expresses himself as follows concerning the temperature of the snow:—"On the high Alps the surface "of the snow freezes during the night, when the "weather is fine, at all seasons of the year. This "congelation is but superficial on glaciers raised only

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température atteint son maximum d'élévation, et le résultat n'a pas une seule fois été favorable à la fusion, le thermomètre est toujours resté au-dessous de zéro.

Pendant un séjour de plus de 15 jours fait dans le mois de juillet au col du Géant, dans une station qui n'est élevée que de 10,578 pieds au-dessus du niveau de la mer, il a tous les soirs trouvé la congélation, ou la neige ou la grêle; et la température de cette moitié de juillet a été à très-peu près celle du mois de janvier de la ville de Genève, d'où l'on peut, ce me semble, conclure qu'à des hauteurs plus grandes la fusion est non-seulement insensible, mais entièrement nulle. Ce n'est pas assez; les observations faites dans le même lieu ont prouvé qu'il y avait encore congélation à la surface de la neige même, quand le thermomètre donnait à l'air atmosphérique plus d'un degré de chaleur. Voici comment il s'exprime sur la température des neiges: "Sur les hautes Alpes la surface de la neige "gèle pendant la nuit, lorsque le temps est clair, dans toutes les "saisons de l'année. Cette congélation n'est que superficielle "sur les glaciers élevés seulement de 900 ou de 1,000 toises au-

"900 or 1,000 toises above the sea; but at the height "of 1,200 toises, and above, the snow hardens to "a depth of several inches; it thus forms at the surface "a crust sufficiently solid to support men. Under "this frozen crust the snow remains at zero, or at the "freezing point."*

It will not be objected that there may be melting in the interior of the glacier; for it is a property which I believe to be inherent in ice, at least when perfectly compact, to preserve a temperature constantly below the freezing point. The reason is simple: all the caloric directed upon the ice is used up at the surface in there effecting a melting proportional to its quantity; when the melting is effected, the molecule of water carries off and keeps the caloric, which is absolutely necessary for it in order that it may maintain its condition, and never can a ray of heat get beyond the first surface of ice to raise the temperature of the interior. Thus, just as fresh quantities of caloric supplied to boiling water are employed in producing evaporation without

* *Voyage dans les Alpes*, tome 4, p. 251.

"dessus de la mer; mais à la hauteur de 1,200 toises et au-"dessus, la neige se durcit à la profondeur de plusieurs pouces; "il se forme ainsi à la surface une croûte assez solide pour "porter des hommes. Sous cette croûte gelée la neige demeure "à zéro ou au terme de la congélation." *

On ne m'objectera pas qu'il peut y avoir fusion dans l'intérieur des glaciers; car c'est une propriété que je crois inhérente à la glace, du moins quand elle est parfaitement compacte, de conserver une température que est constamment au-dessous de zéro. La raison en est simple: tout le calorique dirigé sur la glace est employé à la surface pour y opérer une fusion proportionnelle à sa quantité; quand la fusion est opérée, la molécule d'eau emporte et garde le calorique qui lui est strictement nécessaire pour son état, et jamais un rayon calorifique ne peut dépasser la première surface de la glace pour élever la température de l'intérieur. Ainsi, de même que les nouvelles quantités de calorique fournies à l'eau bouillante sont employées à la vaporisation, sans pouvoir élever au-dessus la

* *Voyage dans les Alpes*, tome 4, page 251.

being able to raise the temperature of the water, so the quantities of caloric supplied to ice are employed in producing melting without ever being able to raise the ice above the freezing point. There cannot therefore be melting in the interior of glaciers. Of course I do not speak of cases where there may be currents of air through fissures.

In short, even though no one had even yet reached our ice-peak, we might have come to the conclusion, from the notions acquired in meteorological research, that no melting can there take place. We know that the mean temperature decreases rapidly as we ascend. Very general observation leads us to believe that for every hundred toises of elevation the temperature is lowered by $2\frac{1}{4}°$ Fahrenheit, keeping to the same latitude. Starting, therefore, from the level of the ocean, where the mean temperature is about 59° above the freezing point, and rising 2,450 toises, so as to reach the level of the summit of Mont Blanc, we should have a fall of 55° to arrive at the mean temperature of the higher glaciers, which would place this mean at 4° Fahrenheit.

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température de l'eau; de même les quantités de calorique fournies à la glace sont employées à la fusion, sans jamais pouvoir élever la glace au-dessus de zéro. Il ne peut donc y avoir fusion à l'intérieur des glaciers. On sent que je ne parle pas du cas où il y aurait des courants d'air par des fissures.

Enfin, quand même personne ne serait encore parvenu sur ce sommet glacé, on aurait pu décider, par les notions acquises en météorologie, que la fusion ne peut y avoir lieu. On sait que la moyenne température baisse assez rapidement à mesure que l'on s'élève. Les observations les plus générales portent à croire que pour chaque centaine de toises d'élévation, la température moyenne baisse d'un degré de R. en suivant la même latitude. En partant donc du niveau de l'Océan, où la température moyenne est d'environ + 12°, et en s'élevant de 2,450 toises pour arriver jusqu'au sommet du Mont-Blanc, on aurait un abaissement de 24° pour arriver à la température moyenne des glaciers supérieurs, ce qui porterait cette moyenne à 12° au-dessous de zéro.

Experiment proves, moreover, that the more we rise the less apart are the extremes of temperature; and according to this principle, the extreme of heat could never rise above the freezing point by a quantity sufficient to produce melting.

There are circumstances with respect to the melting of ice which are not yet known. Some experiments have proved to me that snow absorbs a large quantity of caloric before passing into a melting state.

I filled with powdery snow which had fallen when the temperature was $20\frac{3}{4}°$ Fahrenheit, a cylinder of glass two inches in diameter and five inches in height; I placed this cylinder opposite a fire at a point where the thermometer stood at 77°. Melting was not perceptible at once; but after more than five minutes the cylinder of snow was contracted by a third part, though still cylindrical; its diameter was diminished by about as much—that is to say, there was contraction throughout the snow in the direction of its centre, and then melting commenced.

L'expérience prouve encore que plus on s'élève, plus les extrêmes de température sont rapprochés, et d'après ce principe, l'extrême du côté de la chaleur ne pourrait jamais dépasser zéro d'une quantité suffisante pour produire la fusion.

Il y a, relativement à la fusion de la glace, des circonstances qui ne sont pas encore connues. Quelques expériences m'ont prouvé que la neige absorbe une grande quantité de calorique avant d'entrer en fusion.

J'ai rempli de neige pulvérulente tombée par un froid de 5 degrés au-dessous de zéro,* un cylindre de verre de deux pouces de diamètre et de cinq de hauteur; j'ai placé ce cylindre vis-à-vis d'un foyer, sur un point où le thermomètre marquait + 20°. La fusion ne s'est point d'abord manifestée; mais pendant plus de cinq minutes le cylindre de neige s'est raccourci d'un tiers sans cesser d'être cylindrique; son diamètre a diminué à peu près d'autant; c'est-à-dire qu'il y a eu contraction dans toute la neige vers son centre, et ensuite a commencé la fusion.

* Toutes mes indications de température sont faites d'après le thermomètre de Réaumur.

Something similar happens with ice. When we wish to fill an ice-house we break the ice brought thither into very small fragments, then we water it with water whose temperature is about 50° Fahrenheit, and yet the whole is converted into a compact mass of ice; there is in this case a considerable consumption of caloric, which not only has not been made use of in melting, but which has not even arrested congelation in a place where the atmosphere was above the freezing point. This explains a fact well recognized by observers: when the earth has been covered with a certain quantity of snow, we see at the end of a few days that this layer is diminished in thickness by one half or even more, though there has been neither melting, rain, nor wind. This diminution of volume is usually explained by evaporation, and by the pressure of the snow upon itself; without denying the action of these two causes, I believe that the chief one is adhesion, and in the experiment I have quoted, this action, favoured by the softening of the snow exposed to heat, does but exhibit itself in a more instantaneous manner.

In short, according to all the descriptions that M. de

Il se passe quelque chose de semblable pour la glace. Quand on veut remplir une glacière, on brise la glace que l'on y porte en très-petits fragments, ensuite on l'arrose avec de l'eau dont la température est d'environ huit degrés au-dessus de zéro, et pourtant le tout se convertit en une masse compacte de glace; il y a eu dans ce cas un emploi considérable de calorique, qui, non-seulement n'a pas été employé à la fusion, mais qui n'a pas même arrêté la congélation dans un endroit où l'atmosphère était au-dessus de zéro. Ceci nous explique un fait bien reconnu des observateurs: quand la terre a été couverte d'une certaine quantité de neige, on voit au bout de peu de jours cette couche s'amincir de moitié et même plus, sans qu'il y ait eu ni fusion, ni pluie, ni vent. On explique cette diminution de volume par la vaporisation et par la pression de la neige sur elle-même; sans nier l'action de ces deux causes, je crois que la principale vient de l'affinité, et dans l'expérience que j'ai citée, cette action, favorisée par le ramollissement de la neige exposée a la chaleur, ne fait que se manifester d'une manière plus instantanée.

Enfin d'après toutes les descriptions que M. de Saussure

Saussure gives of the glaciers, they are composed of different layers, super-imposed upon one another, and their density increases with the depth of the layers, so that those which touch the surface of the rocks on which they rest are of compact ice, white and fairly transparent; but since ice is not permeable to water, it follows that even though there should be occasional melting on the upper part, the water resulting therefrom could only descend to be frozen on the first impermeable layer—a state of things which could not constitute a cause of decrease in the case of the higher glaciers. It seems to me, therefore, to be demonstrated that melting (which is *nil* in the case of reservoir glaciers) begins only in the region of stream glaciers.

The second cause of decrease is evaporation, which the absence of caloric must reduce to a trifle in the regions of eternal ice.

The third cause is wind: this is a very powerful one. When, after a fall of snow on the summit of Mont Blanc, a cold wind prevails, it sweeps all the mountain tops, and clouds of dust are seen to de-

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donne des glaciers, ils sont composés de diverses couches étendues les unes sur les autres, et leur densité augmente avec la profoundeur des couches, de sorte que celles qui touchent la surface des rochers sur lesquels elles reposent, sont de la glace compacte, blanche et assez transparente; mais comme la glace n'est point perméable à l'eau, il s'ensuit que lors même qu'il y aurait quelquefois fusion à la partie supérieure, l'eau qui en résulterait ne ferait que descendre pour se congeler sur la première couche imperméable, ce qui ne constituerait point une cause de décroissement pour les glaciers supérieurs. Il me paraît donc démontré que la fusion, nulle pour les glacier-réservoirs, ne commence que dans la région des glaciers d'écoulement.

La deuxième cause de décroissement est la vaporisation, que l'absence du calorique doit réduire à peu de chose dans les régions des glaces éternelles.

La troisième cause est le vent; celle-ci est d'une assez grande puissance. Quand, après la chute de la neige sur le sommet du Mont-Blanc, vient à régner un vent froid, il balaie toutes les sommités, et l'on voit se détacher du haut des

tach themselves from the upper parts of the glaciers, and to whirl round in the air, or to start from the highest point and betake themselves to a distance, spreading as they go like the tail of a comet. It is then said that Mont Blanc is *smoking his pipe.* In summer this snow-dust comes and is melted in the lower regions of the atmosphere, and in winter it collects in the bottom of the valleys; subtle and borne by the wind, it penetrates into cottages by the smallest openings; it is not uncommon to find more than a foot of it beneath the keyhole of the door. This cause, however, is not constantly at work; and when the snow is condensed, or when covered with a glassy coating, the wind cannot scatter it. We must therefore seek some other cause of decrease to account for the fact that glaciers remain permanently at a given height.

Those who dwell in the neighbourhood of the glaciers, all those who have visited them, and those especially who have made or only attempted the ascent of Mont Blanc, have pointed out the cause in question, without exactly looking upon it as such,—avalanches, namely, and descending streams of ice.

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glaciers des nuages de poussière qui tourbillonnent dans les airs, ou qui partent du point le plus élevé et s'éloignent en divergeant comme la queue d'une comète. On dit alors que le Mont-Blanc *fume sa pipe.* En été, cette poussière de neige vient se fondre dans les régions inférieures de l'atmosphère, et en hiver elle s'entasse dans le fond des vallées; subtile et emportée par le vent, elle pénètre dans les chaumières par les moindres ouvertures; il n'est pas rare d'en trouver plus d'un pied au-dessous du trou de la serrure d'une porte. Cependant cette cause n'est pas perpétuellement agissante, et quand la neige est contractée ou qu'elle est recouverte d'une surface vitreuse, le vent ne peut la disperser. Il faut donc chercher une autre cause de décroissement pour rendre raison de la permanence des glaciers dans une élévation donnée.

Ceux qui habitent autour des glaciers, tous ceux qui les ont visités, et ceux surtout qui ont effectué ou seulement tenté des ascensions au sommet du Mont-Blanc, ont indiqué cette cause sans précisément la regarder comme telle: ce sont les avalanches et les écoulements de glace.

CHAPTER V.

PASSAGE OF SNOW INTO ICE.

A PHENOMENON which appears incontestable is the passage, or rather the conversion, of snow into ice. According to the reports of all travellers, the visible surface of the glaciers is of snow, more or less hard according to the weather in which it is examined. They have found *ice* only accidentally in crevasses, on the edges of the glaciers, or in the beds of avalanches.

According to M. de Saussure, the ice which constitutes the lower glaciers is harder and more compact than that which is met with higher up; its hardness diminishes as the height increases. "The "solidity of the ice decreases gradually as we ascend "towards the higher parts; and on the very sum- "mits, at least if they are isolated, we never find any- "thing but snow."* But that which is snow on the

* *Voyage dans les Alpes*, tome 1, p. 373.

CHAPITRE V.

PASSAGE DE LA NEIGE À LA GLACE.

Un phénomène qui paraît incontestable, c'est le passage ou plutôt la conversion de la neige en glace. D'après le rapport de tous les voyageurs, la surface visible des glaciers est de la neige plus ou moins dure, selon le temps où on l'examine. Ils n'ont trouvé la glace qu'accidentellement dans les crevasses, sur les flancs des glaciers ou dans le lit des avalanches.

D'après M. de Saussure, la glace qui forme les glaciers inférieurs est plus dure, plus compacte que celle qui se rencontre plus haut; sa dureté va diminuant à mesure qu'elle s'élève. "La solidité de la glace décroît par degré à mesure "que l'on remonte vers le haut; et sur les sommités mêmes, "si du moins elles sont isolées, on ne trouve jamais que des "neiges."* Mais ce qui est neige à la surface devient glace

* *Voyage dans les Alpes*, tome 1, page 373.

surface becomes ice in the lower beds, and the transition appears to be imperceptible enough. The following are the words of M. de Saussure, in speaking of different masses of ice which had come down from the *Dôme-du-Goûté*. He gives to these masses the name of *seracs*:—

"It was, however," says he, "a pleasure to observe "these seracs which one seldom has the opportunity of "seeing so close at hand. I measured some which "were more than 12 feet in each direction; the base— "that is to say, the part which had been contiguous to "the rock—was an ice with small air bubbles, trans- "lucent, white, hard, and more compact than that of "ordinary glaciers; the opposite face, which had "originally been the upper one, was still of snow, "although a little hardened; and in the same block "were seen all the shades between these two extremes."* Whence it may be concluded that weather favourable to the action of adhesion simultaneously with the pressure of the layers upon each other, bring together the little crystals which constitute the snow, and by bringing them into contact make them pass into the state of ice.

* *Voyage dans les Alpes*, tome 4, p. 163.

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dans les couches inférieures, et la passage paraît assez insensible. Voici ce qu'en dit M. de Saussure en parlant de diverses masses de glace qui étaient descendues du *Dôme-du-Goûté*. Il donne à ces masses le nom de *seracs*.

"J'eus cependant, dit-il, du plaisir à observer ces seracs que "l'on a rarement occasion de voir d'aussi près. J'en mesurai "qui avaient plus de 12 pieds en tous sens; le fond, soit la partie "qui avait été contiguë au roc, était une glace à petite bulles, "translucide, blanche, dure, plus compacte que celles des "glaciers ordinaires; la face opposée qui avait été originaire- "ment la face supérieure, était encore de la neige quoique un "peu durcie; et on voyait dans le même bloc toutes les "nuances entre ces deux extrêmes."* D'où l'on peut conclure que le temps favorisant l'action de l'affinité et en même temps la pression des couches les unes sur les autres, rapprochent les petits cristaux qui forment la neige, et en les amenant au contact, les font passer à l'état de glace. Cependant, comme

* *Voyage dans les Alpes*, tome 4, page 163.

As, however, there is contraction between the different portions of the whole, it seems that lateral fissures must be produced, and when the mass is set in motion by avalanches, it must break up first in the seams separating the layers, and then by means of the lateral fissures formed by contraction. It is this, doubtless, which gives rise to those blocks of ice which have the regular form of a quadrilateral. It must be a true crystallization. I have seen on the sides of the Glacier de Bionnassay, which falls into the Valley of Montjoie, slices of ice resting one upon the other like courses of masonry, differing totally in colour, texture, and density. The upper beds are of consolidated snow, and of a dirty white; as they come lower, the ice becomes more compact, and takes the greenish colour which appears to belong to it.

In the middle regions, where melting goes on up to a certain point, the water produced by this means filters through the snow, there solidifies and turns it into ice. This is a fact known in the Alps: whenever you come across a large avalanche which has resisted the heats of summer, and which is inclosed in a basin where the

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il y a contraction entre les parties de l'ensemble, il paraît qu'il doit s'opérer des fissures latérales, et quand la masse est mise en mouvement par les avalanches, elle doit se diviser d'abord dans les joints qui séparent les couches, et ensuite par les fissures latérales formées par le retrait. C'est sans doute ce qui donne lieu à ces blocs de glace qui ont la forme régulière du quadrilatère. Ce serait une véritable cristalisation. J'ai vu sur les flancs du glacier de Bionacey qui tombe dans la vallée de Montjoie, des tranches de glace reposant les unes sur les autres en forme d'assises tout-à-fait différentes par la couleur, la contexture et la densité. Les couches supérieures sont une neige agglomérée et d'un blanc sâle; à mesure qu'elles descendent, la glace devient plus compacte et prend la couleur verdâtre, qui paraît être la sienne.

Dans les régions moyennes où la fusion s'opère jusqu'à un certain point, l'eau produite par ce moyen s'infiltre à travers les neiges, s'y solidifie et les change en glace. C'est un fait connu dans les Alpes: toutes les fois que vous recontrez une grande avalanche qui a résisté aux chaleurs de l'été et qui est

water can stay, your guides say, "This snow will be ice next spring." In the lower regions, where melting of the glaciers takes place, the water which flows over this porous ice in little rivulets polishes it and restores to it its tender green colour which it does not ordinarily possess; one would say that these little streams were flowing in channels of aqua-marine or beryl.

Thus, to sum up this chapter, I think we may conclude that the metamorphosis of snow into ice is effected—1stly, by the rain which falls on the snow. 2ndly, by the vapours which are condensed at the surface of the snow. 3rdly, by the softening of snow by the sun. 4thly and lastly, by pressure, which I look upon as the most potent cause.

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renfermée dans un fond où l'eau peut s'arrêter, vos guides disent: ces neiges seront des glaces au printemps prochain. Dans les régions inférieures où il y a fusion des glaciers, l'eau qui coule par de petites rigoles sur cette glace bulleuse, la polit et lui rend sa couleur verte (*sic*) tendre qu'elle n'a pas ordinairement; on dirait que ces petits ruisseaux coulent dans des conduits d'aigue-marine ou de béril.

Ainsi, pour résumer ce chapitre, je crois pouvoir conclure que la métamorphose de la neige en glace s'opère, 1° par la pluie qui tombe sur la neige, 2° par les vapeurs qui se condensent à la surface de la neige, 3° par le remollissement des neiges par le soleil, 4° enfin par la pression, que je regarde comme le moyen le plus efficace.

CHAPTER VI.

OF AVALANCHES AND ICE FLOWS.

THE summit of Mont Blanc is a slightly rounded crest, which has steep slopes on every side. That which is conventionally called a plateau is only a slope less steep than the others. What we say here of Mont Blanc must be understood also of the most elevated surfaces of all mountains, but especially of primitive mountains, which generally end in peaks more or less close to one another. Limestone mountains, which have more uniform summits, have nevertheless also a pretty steep slope, formed by the uplifting of the upper strata. When snow has accumulated for some time on these slopes, its own weight compels it to fall down the flanks of the mountain; this is what is called an avalanche. When the slope is more gentle and approaches to a horizontal line, beds of snow resting for a long time on one another give rise to the formation

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CHAPITRE VI.

DES AVALANCHES ET DES ÉCOULEMENTS.

Le sommet du Mont-Blanc est une crête un peu arondie qui a des pentes de tous les côtés. Ce que l'on est convenu d'appeler plateau, n'est qu'une pente moins rapide que les autres. Ce que nous disons ici du Mont-Blanc doit s'entendre aussi de la surface la plus élevée de toutes les montagnes, mais surtout des montagnes primitives, qui se terminent le plus ordinairement par des aiguilles plus ou moins rapprochées. Les montagnes calcaires, qui ont des sommités plus uniformes, ont cependant aussi un versant assez rapide formé par le redressement des couches supérieures. Lorsque la neige s'est accumulée pendant quelque temps sur ces pentes, son propre poids la détermine à tomber le long des flancs de la montagne; c'est ce que l'on appelle avalanches. Lorsque la pente est plus douce et se rapproche de la ligne horizontale, les couches de neige reposant pendant long-temps les unes sur les autres, donnent lieu à la

of ice ; and it is only on the edges of the glacier that blocks of ice detach themselves little by little and fall to the bottom of the precipice.

When ice crowns a summit with a perpendicular face, the ice dragged by its own weight comes beyond the edge of the rock, advances over the precipice in the form of the eaves of a house, and when its solidity is no longer a match for the weight of this mass, breaks off, shatters itself against the sides of the rocks, and falls almost in powder into the neighbouring valleys.

When the slope is gentle and uniform down to the bottom of a valley, the ice flows gently down, without any of the great catastrophes which accompany avalanches, only there are sometimes ruptures between the ice which descends and that which is still held back by obstacles. All travellers who have reached the higher glaciers have been witnesses of these avalanches, of these falls, of these forward movements. There are few days in the year when these high mountains do not resound with the cracking noise of the ice as it splits, and with the crash of that which falls ; here, then, we have the true causes of decrease

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formation de la glace, et ce n'est que sur les bords du glacier que viennent peu à peu se détacher des blocs de glace qui descendent au fond des précipices.

Lorsque les glaces couronnent une crête taillée à pic, la glace entraînée par son propre poids déborde le rocher, s'avance sur le précipice en forme d'avant-toit, et quand sa solidité ne fait plus équilibre à la pesanteur de cette masse, elle se rompt, se brise centre les flancs des rochers, et tombe presque en poussière dans les vallées environnantes.

Lorsque la pente est radoucie et uniforme jusqu'au fond des vallées, la glace y coule lentement sans aucune des grandes catastrophes qui accompagnent les avalanches, seulement il y a quelquefois des ruptures entre la glace qui descend et celle qui est encore retenue par des obstacles. Tous les voyageurs qui sont parvenus dans les glaciers supérieurs ont été témoins de ces avalanches, de ces chutes, de ces avancements. Il y a peu de jours dans l'année où ces hautes montagnes ne retentissent pas du craquement des glaces qui se fendent et du fracas de celles qui tombent : voilà quelles sont les véritables causes de

in the higher glaciers. This snow, and this ice, which are detached from the cold summits of the mountains, are like the overflow which issues from a reservoir; it is a surplus which starts on its way to be melted in a temperate region, and this surplus must always be nearly equal to the fall of rain and snow, and to the condensation of vapour; it is by means of this kind of equilibrium that the height of Mont Blanc must remain always the same, although the snows never melt there.

Nature has herself assumed the task of giving to this theory of the flow of glaciers a demonstration which the mind cannot refuse to accept; it is this,—the upper part of Mont Pourri, which bounds the valley of Tignes in Tarantaise, presents a plateau of great extent and covered with a strong crust of ice, which, instead of flowing down by gullies along the sides of the mountain, descends in cascades from the summit of perpendicular rocks. The glacier of Lagurraz is one of the most curious among those of the Alps. At ten minutes distance from the village of Lagurraz, the mountain presents an escarpment of more than 600 feet in height.

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décroissement des glaciers supérieurs. Ces neiges et ces glaces qui se détachent des froides sommités des montagnes, sont comme *le trop plein* qui sort d'un réservoir, c'est un excédant qui part pour aller se fondre dans une région tempérée, et cet excédant doit tojours être à peu près égal à la chute des pluies, des neiges, et à la condensation des vapeurs: c'est par cette espèce d'equilibre que la hauteur du Mont-Blanc doit être toujours la même, quoique que les neiges n'y fondent pas.

La nature s'est chargée elle-même de donner à cette théorie de l'écoulement des glaciers une démonstration à laquelle l'esprit ne peut se refuser; la voici: le haut du Mont-Pourri qui borde la vallée de Tignes en Tarantaise, présente un grand plateau et recouvert d'une puissante croûte de glace qui, au lieu de s'écouler par des couloirs le long des flancs de la montagne, descend par cascades du sommet des rochers taillés à pic. Le glacier de Lagurraz est un des plus curieux parmi ceux des Alpes. A dix minutes de distance du village de Lagurraz, la montagne présente un escarpement de plus de six cents pieds d'élévation. A cette hauteur, la tranche vive du rocher

At this height, the living section of these rocks is continued by the living section of the upper ice, which appears to be about a hundred and fifty feet thick. As the ice is formed on the plateau, the excess over what the reservoir glacier can contain advances laterally over the edge of the precipice, and when the weight of the part which projects beyond the edge overcomes the force of cohesion which unites the particles of the ice, it breaks off, and falls to the foot of the mountain, into a hollow which is always full of it; there it melts without spreading further, and gives rise to a torrent whose source has no remoter origin. It is an intermittent source of ice, producing a continuous source of water.

In seeking for the causes of the diminution of glaciers, it has occurred to me that it may possibly be that ice, in spite of its hardness and rigidity, cannot support more than a given pressure without being broken or stretched. On this supposition, whenever the pressure should exceed this force, breaking would take place, and for the same reason, ice-flows. Let us take at the summit of the plateau of Mont Blanc a column of ice resting on a horizontal base. The ice which forms the

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est continuée par la tranche vive des glaces supérieures qui paraissent avoir environ cent cinquante pieds d'épaisseur. A mesure que la glace se forme sur le plateau, l'excédant de ce que peut contenir le glacier-réservoir s'avance par côté, sur le bord du précipice, et quand le poids de la partie qui déborde vient à dépasser la force de cohésion qui unit entre elles les parties de la glace, elle se rompt et tombe au pied de la montagne, dans un creux qui en est toujours plein; là elle se fond sans s'étendre davantage, et donne lieu à un torrent dont la source ne remonte pas plus loin. C'est une source intermittente de glace qui produit une source continue d'eau.

En recherchant les causes de la diminution des glaciers, il m'est venu dans l'esprit qu'il serait possible que la glace, malgré sa dureté et sa rigidité, ne pût supporter sans se briser ou s'étendre qu'une pression donnée. Dans cette supposition, toutes les fois que la pression dépasserait cette force il y aurait rupture des glaces, et par là-même écoulements. Prenons au sommet du plateau du Mont-Blanc une colonne de glace reposant sur une base horizontale. La glace qui forme la

first layer of this column is compressed by the weight of all the layers above it; but, if the solidity of the first layer could only support a weight equal to 100, as soon as the weight should exceed this amount, there would be rupture and separation of the ice at the base. Now, something pretty much of this sort takes place in the immense crust of ice which covers the upper parts of Mont Blanc. This crust appears to increase by the upper surface, and to diminish by the sides. To satisfy oneself whether the flow is due to the force of pressure, it would be necessary to make a series of experiments on the solidity of ice, which have not yet been attempted.

CHAPTER VII.

CONCERNING STREAM-GLACIERS.

Of all the movements which glaciers undergo, the most interesting, and at the same time the most

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première assise de cette colonne est comprimée par le poids de toutes les assises supérieures; mais si la solidité de cette première assise ne pouvait supporter qu'un poids égal à 100, dès que le poids dépasserait ce terme, il y aurait rupture et écartement dans la glace de la base. Or, il se passe quelque chose d'assez semblable dans l'immense croûte de glace qui recouvre les sommités du Mont-Blanc. Cette croûte paraît s'accroître par la surface supérieure et diminuer par les côtés. Pour s'assurer si l'écoulement est dû à la force de pression, il faudrait faire sur la solidité de la glace une suite d'expériences qui n'ont point encore été tentées.

CHAPITRE VII.

DES GLACIERS D'ÉCOULEMENT.

De tous les mouvements qu'éprouvent les glaciers, le plus intéressant et en même temps le plus difficile à concevoir est le

difficult to conceive, is the slow, insensible, and, to all appearance, permanent motion of stream glaciers, of those rivers of solid water which we see descending in a straight line, or winding from the edges of the reservoir glaciers into the valleys inhabited by man. The sight of these immense flows of ice, which advance between banks covered with flowers, forces upon the mind thoughts of eternity, of Providence, and of death, which elevate and sadden the soul. I stopped near a field of rye which was by the side of the Glacier des Bossons. An ear, almost ripe, and swayed by the wind, each instant touched the ice, and drew back as if frightened by this strange guest come from a climate which has no power save for death.

Let us return to the origin of the lower glaciers which I call stream glaciers. The upper parts of Mont Blanc bristle with granite aiguilles, with rocky ridges which hold back the ice, and prevent it from flowing equally over every side of the mountain; but between these aiguilles, between these ridges of rock, there are a kind of valleys, of gullies, which act as channels for the exit of the ice of the reservoir. These channels,

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mouvement lent, insensible, et, selon toutes les apparences, permanent, desglaciers d'écoulement, de ces fleuves d'eau solide que l'on voit descendre en ligne droite ou serpenter du bord des glaciers-réservoirs jusque dans les vallées habitées par l'homme. La vue de ces immenses coulées de glace, qui s'avancent entre des rives couvertes de fleurs, jette dans l'esprit des pensées de perpétuité, de providence et de mort qui élèvent et attristent l'ame. Je m'arrêtai vers un champ de seigle qui était à côté du glacier des Bossons. Un épi presque mur et balancé par le vent allait à chaque instant toucher la glace et revenait sur lui-même, comme effrayé par cet hôte étranger venu d'un climat qui n'a de puissance que pour la mort.

Revenons à l'origine des glaciers inférieurs, que j'appelle glaciers d'écoulement. Les sommités du Mont-Blanc sont hérissées d'aiguilles granitiques, d'arêtes rocheuses qui retiennent les glaces et les empêchent de couler également sur tous les flancs de la montagne; mais entre ces aiguilles, entre ces arêtes de rochers, il y a des espèces de vallées, des couloirs qui servent de canaux pour la sortie des glaces du réservoir. Ces canaux,

which are numerous at the place of escape from even the higher glaciers, re-unite little by little as they descend towards the valleys.

If it were necessary to demonstrate that the lower glaciers are fed by the higher glaciers, it would be sufficient to submit to the reader a collection of facts from which this truth results quite as of course.

Firstly. These glaciers are placed in a region in which the melting of ice being more considerable than the supply, the glacier would necessarily be destroyed if there were not a source of alimentation. For even supposing, in such a locality, a primitive mass of ice brought thither by avalanches or by other causes, there would always be a time when the total destruction of the glacier must come about, since, after having melted the ice of the year, there would always be an excess of caloric to attack and diminish each year the ice which I call primitive, because it does not result from the annual falls.

Secondly. Whenever we meet with a permanent glacier in the region that, in order to indicate its temperature, I shall call cereal, we can, without a chance

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qui sont nombreux à la sortie même des glaciers supérieurs, se réunissent peu à peu en descendant vers les vallées.

S'il était nécessaire de démontrer que les glaciers inférieurs sont alimentés, entretenus par les glaciers supérieurs, il suffirait de remettre sous les yeux du lecteur un ensemble de faits d'où cette vérité découle tout naturellement.

1° Ces glaciers sont placés dans une région où la fusion des glaces étant plus considérable que la formation, il y aurait nécessairement destruction du glacier s'il n'y avait pour eux une source alimentaire. Car même en supposant dans cette localité un amas primitif de glace apportée par des avalanches ou par d'autres causes, il y aurait toujours un temps où arriverait la destruction totale du glacier, puisqu'après avoir fondu la glace de l'année, il y aurait encore un excédant de calorique pour attaquer et diminuer chaque année la glace que j'appelle primitive, parce qu'elle ne proviendrait pas des chutes annuelles.

2° Toutes les fois que l'on rencontre un glacier permanent dans la région que j'appellerai céréale, pour indiquer la temp-

of being mistaken, assert beforehand that the other extremity of this glacier abuts upon reservoir glaciers, and that between these two extremes there is no break of continuity. Should nothing else have been demonstrated but this connection, which is an incontestable fact, it would be enough to demonstrate the origin of the lower glaciers.

Observe what M. de Saussure says in speaking of the Glacier des Bossons:—"It is quite certain that there is an unbroken continuity of snow and ice from the top of Mont Blanc down to the end of the Glacier des Bossons." And what he says of that glacier may be said of all others.

Thirdly. The mass of the glacier is in inverse proportion to the slope over which it flows. When the trough is steep, the ice is thin, and its surface is contracted; when the slope decreases and approaches to the horizontal line, the glacier fills out—it becomes like a sea, like a lake between two streams. These facts are easy to verify by the mere inspection of the Glacier des Bois, as seen from the Mont Envers.

Nothing shows better to what an extent the glacier

érature, on peut, sans s'exposer à se tromper, affirmer d'avance que l'autre extrémité de ce glacier aboutit aux glaciers-réservoirs, et qu'entre ces deux extrêmes, il n'existe pas de solution de continuité. Quand il n'y aurait de démontré que cette liaison qui est un fait incontestable, elle suffirait pour démontrer l'origine des glaciers inférieurs.

Voici ce que M. de Saussure dit en parlant du glacier des Bossons: "Il est bien certain qu'il y a une continuité non "interrompue de neige et de glace depuis la cime du Mont-"Blanc jusqu'au bas du glacier des Bossons." Et ce qu'il dit de celui-là, doit se dire de tous les autres.

3° La masse du glacier est en raison inverse de la pente sur laquelle il coule. Quand le couloir est rapide, la glace est mince et sa surface est rétrécie; quand la pente diminue et se rapproche de la ligne horizontale, le glacier se renfle, il devient comme une mer, comme un lac entre deux courants. Ces faits sont faciles à vérifier par la seule inspection du glacier des Bois, vu depuis le Mont-Envers.

Rien ne démontre mieux jusqu'à quel point le glacier se plie

adapts itself to the spot on which it happens to be than the form of the glacier of *Mont Dolent*, in the valley of Ferret: "Its highest plateau is a great "amphitheatre surrounded by lofty flakes of granite "of pyramidal form; thence, the glacier descends by a "gorge, into which it is compressed; but as soon as it "has passed beyond it, it widens out anew and opens "like a fan: it has therefore, as a whole, the form of "a sheaf contracted in the middle and spread out at its "two extremities."*

There are a host of facts that would seem to induce the belief that the substance of glaciers enjoys a kind of ductility which allows it to mould itself upon the locality which it occupies—to thin out, to swell, to contract, and to spread as a soft paste would do. Nevertheless, when we deal with a piece of ice, when we strike it, we find in it a rigidity which is in direct opposition to the appearances of which we have just spoken. Perhaps experiments made upon larger masses would give other results.

Fourthly. The vaster is the channel of discharge at

* *Voyage dans les Alpes*, tome 2, page 247.

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au local sur lequel il se trouve, que la forme du glacier du *Mont-Dolent* dans la vallée de Ferret: "Son plateau le plus "élevé est un grand cirque entouré de hauts feuillets de granite, "de forme pyramidale; de là, le glacier descend par une gorge, "dans laquelle il est resserré; mais dès qu'il l'a dépassée, il "s'élargit de nouveau et s'ouvre en éventail: il a donc en tout "la forme d'une gerbe serrée dans le milieu et dilatée à ses deux "extremités."*

Il y a une foule de faits qui sembleraient faire croire que la substance des glaciers jouit d'une espèce de ductilité qui lui permet de se modéler sur la localité qu'elle occupe, de s'amincir, de se renfler, de se rétrécir et de s'étendre comme le ferait une pâte molle. Cependant, quand on agit sur un morceau de glace, qu'on le frappe, on lui trouve une rigidité qui est en opposition directe avec les apparences dont nous venons de parler. Peut-être que les expériences faites sur de plus grandes masses donneraient d'autres résultats.

4° Plus le canal de dégorgement est vaste à la sortie du

* *Voyage dans les Alpes*, tome 2, page 247.

the point of exit from the reservoir glacier, or, what comes to the same thing, the more tributary glaciers a principal glacier receives into its bed, the farther does it advance into the bottom of the valley, because in that case the quantity of ice being greater, the consumption of caloric in the process of melting must be proportioned to it, and consequently the stream of ice has time before being melted to penetrate farther into the cereal region. The Glacier des Bois, which receives into its bed the outflows of three great glaciers, that of the Tacul, that of Lechaux, and that of the Talêfre, is likewise one of those that advance farthest towards the bottom of the valley.

Fifthly. There are several *indicia* which prove the motion of the glaciers in the ravines that serve as their beds; I shall point out but two of them. If we take note of some point on the glacier that can be recognized by a crevasse or a pyramid of ice, or even by one of the blocks of rock that are found on the surface, and if we fix its position by a line which terminates in the two sides of the valley, we shall be astonished some months later at no longer finding the point in question on the line that defined its position; but it will have advanced

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glacier-réservoir, ou, ce qui revient au même, plus un glacier principal reçoit dans son lit de glaciers particuliers, plus il s'avance dans le fond des vallées, parce qu'alors la quantité de glace étant plus grande, l'emploi du calorique pour la fusion doit lui être proportionné, et par conséquent la coulée de glace avant d'être fondue a le temps de pénétrer plus avant dans la région céréale. Le glacier des Bois, qui reçoit dans son lit les écoulements de trois grands glaciers, celui du Tacu (*sic*), celui de Lechaux et celui du Talêfre, est aussi l'un de ceux qui s'avancent le plus vers le fond de la vallée.

5° Il y a plusieurs indices qui prouvent le mouvement des glaciers dans les couloirs qui leur servent de lit; je n'en indiquerai que deux. Si l'on remarque un point du glacier reconnaissable par une crevasse ou une pyramide de glace, ou même par un des blocs de rocher qui se trouvent à la surface, et que l'on fixe sa situation par une ligne qui aboutisse aux deux côtés de la vallée, on sera étonné quelques mois après de ne plus trouver le point indiqué sous la ligne qui établissait sa

towards the lower end of the valley, by a quantity which will have relation to the length of the experiment, the temperature, the quantity of water that has fallen on the reservoir glacier: and even to the inclination of the ravine. I was shown, on the edge of the Glacier des Bois, a huge rock of granite which had advanced about 242 feet in the course of a year.

In 1818, the part of the glacier which is towards the Mer de Glace advanced 442 feet. In 1817, the ice advanced nearly a foot a day. I had fixed in 1838 the position of two blocks of rock which lay on the surface of the Glacier des Bois; a year after, I went to measure the distance they had passed over; the one had advanced about 400 feet, and the other had disappeared, whether having fallen into a crevasse formed near it, or having fallen over the edge of the glacier, as we shall see happens often enough.

Sixthly. At the place where a glacier comes to an end, that is to say, at the point of its course at which it has reached the temperature necessary for it to undergo total melting, we always see an accumulation, more or

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position; mais il aura avancé vers le bas de la vallée d'une quantité qui sera en rapport avec la durée de l'expérience, la température, la quantité d'eau tombée sur le glacier-réservoir, et même avec l'inclinaison du couloir. On m'a montré sur le bord du glacier des Bois un gros rocher granitique qui s'était avancé d'environ deux cents quarante-deux pieds dans le cours d'une année.

En 1818, la partie du glacier qui est vers la mer de glace s'est avancée de quatre cents quarante-deux pieds. En 1817, les glaces avançaient à peu près d'un pied par jour. J'avais fixé en 1838 la position de deux blocs de rochers qui étaient à la surface du glacier des Bois; une année après je suis allé mesurer le chemin qu'ils avaient parcouru; l'un avait avancé d'environ quatre cents pieds, et l'autre avait disparu, soit qu'il fût tombé dans une crevasse formée près de lui, soit qu'il fût tombé sur le bord du glacier; comme nous verrons que cela arrive assez fréquemment.

6° A l'endroit où vient finir un glacier, c'est-à-dire dans le point de sa cours où il a atteint la température qui lui était nécessaire pour subir une fusion totale, on voit toujours un dépôt plus ou moins considérable de toutes les substances qu'il

less considerable, of all the substances which it has brought down. They consist of sand, earth, and rocks of all sizes. If we examine the nature of these rocks, we are, generally speaking, forced to allow that they have no analogy with the ground on which they rest, nor even always with the mountains which border the stream; to find their analogues we must reascend towards the origin of the glaciers, and we must conclude that glaciers travel in the manner of rivers.

Seventhly. Lastly, it is at the lower end of the glacier that we see the most manifest signs of its destruction. Let us content ourselves with describing the lower extremity of the Glacier des Bois, the glacier which most travellers visit. When the hot season comes round, there is formed at the end of the glacier, at the very spot where the waters of the Arveron escape from beneath the ice, a grotto, which, at first narrow and low, is rapidly enlarged under the influence of water, of vapour, and of other atmospheric agents. When the height and extent of this ice-vault has reached the proportions allowed by the solidity of the materials which enter into its construction, it has an extremely

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a charriées. Ce sont des sables, des terres et des rochers de toutes les grandeurs. Si l'on examine la nature de ces rochers, on est, pour l'ordinaire, forcé de convenir qu'ils n'ont pas d'analogie avec le terrain sur lequel ils reposent, ni même toujours avec les montagnes qui bordent le courant; pour retrouver les analogues il faut remonter vers les sources des glaciers, et conclure que les glaciers voyagent à la manière des fleuves.

7° Enfin c'est à l'extrémité inférieure du glacier que l'on voit les signes les plus manifestes de sa destruction. Contentons-nous de décrire l'extrémité inférieure du glacier des Bois, celui que visitent le plus les voyageurs. Quand la saison des chaleurs arrive, il se forme au bout du glacier, à l'endroit même où les eaux de l'Arveron s'échappent de dessous la glace, une grotte qui d'abord étroite et basse, se grandit rapidement sous l'influence de l'eau, de la vapeur et des autres agents atmosphériques. Quand la hauteur et l'étendue de cette voûte de glace a atteint les proportions que peut comporter la solidité des matériaux qui entrent dans sa construction, elle a un aspect extrêmement

imposing aspect. It is a vast portico more than a hundred feet high, let into an immense façade, and surmounted by lofty pyramids of ice. Nay, nothing is more astonishing than this work of the elements, of which nature alone has furnished the plan, and achieved the construction. From the bottom of the cavern escapes with a roar the frothy and yellowish water of the Arveron. When erosion and heat have undermined the foundations of this fusible edifice, it crumbles and falls with a crash which resounds like thunder afar in the valley. The waters carry off the *débris* or melt it on the spot, the vault is formed afresh and falls anew. These falls of ice are, so to speak, of daily occurrence, and yet it is easy to see that the glacier alway comes to an end in the neighbourhood of one and the same point, and experiences between its greatest and its least advancement only variations of which we shall point out the cause farther on.

Were we to reckon the layers of ice detached towards this point of the glacier during a century only, on the supposition that there had been no flow of the ice, we should be obliged to look for the glacier much higher up.

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imposant. C'est un vaste portique de plus de cent pieds d'élévation creusé dans une immense façade, et surmonté de hautes pyramides de glace. Non, rien n'est plus étonnant que ce travail des éléments dont la nature seule a fourni le plan et achevé la construction. Du fond de la caverne s'échappe en mugissant l'eau écumeuse et jaunâtre de l'Arveron. Quand l'érosion et la chaleur ont miné les fondements de ce fusible édifice, il s'écroule avec un fracas qui, pareil à celui du tonnerre, retentit au loin dans la vallée. Les eaux entraînent les débris ou les fondent sur place, la voûte se reforme et tombe de nouveau ; ces chutes de glace sont pour ainsi dire journalières, et pourtant il est facile de voir que le glacier vient toujours aboutir aux environs d'un même point, et n'éprouve entre son plus grand et son plus petit avancement que des variations dont nous indiquerons la cause plus tard.

Quand on ne compterait que les lames de glace détachées vers ce point du glacier pendant un siècle, en supposant qu'il n'y eût pas eu d'écoulement de glace, on serait forcé de chercher le glacier beaucoup plus haut.

The river Arc, which traverses the whole valley of La Maurienne, takes its source under a glacier in the mountains of Bonneval. This stream glacier descends by a ravine at a very high inclination, and there we can observe better than elsewhere the phenomenon of the flow of glaciers. The mass which fills the ravine is divided by transverse clefts, and often after the slip of a lower slice, we see the bottom of the ravine in the interval which separates that slice from the upper slice, which in its turn will soon slip and give place to another.

I have already said that the Glacier des Bois is fed by three glaciers, that of the Talêfre, that of Tacul, and that of Lechaux. Each of these is itself fed by several other glaciers of a third order. M. de Saussure thus describes the glacier of Talêfre: "This glacier rises "step by step up to the foot of an exactly semi-"circular rampart which shuts it in on the north side. "This rampart is formed of extremely lofty granite "peaks which terminate in sharply pointed summits, of "infinitely varied forms. The intervals between these "peaks are filled with glaciers which pour down into "that of the Talêfre."

La rivière de l'Arc qui parcourt toute la vallée de la Maurienne, prend sa source sous un glacier dans les montagnes de Bonneval. Ce glacier d'écoulement descend par un couloir très-incliné, et là on peut mieux qu'ailleurs observer le phénomène de l'écoulement des glaciers. La masse qui remplit le couloir est divisée par des fentes transversales, et souvent après le glissement d'une tranche inférieure, on voit le fond du couloir dans l'intervalle qui la sépare de la tranche supérieure. qui glissera bientôt elle-même pour faire place à une autre.

J'ai déjà dit que le glacier des Bois était alimenté par trois glaciers, celui du Talêfre, de Tacu (*sic*) et de Lechaux. Chacun de ceux-ci est lui-même alimenté par plusieurs autres glaciers d'un troisième ordre. Voici comment M. de Saussure décrit le glacier du Talêfre: "Ce glacier s'élève par gradation jusqu'au "pied d'une enceinte exactement demi-circulaire qui le ferme "du côté du nord. Cette enceinte est formée par des pics de "granite extrêmement élevés qui se terminent par des som-"mités aiguës, de formes infiniment variées. Les intervalles "de ces pics sont remplis par des glaciers qui viennent se verser "dans celui du Talêfre."

The same author saw, in the valley of Ferret, a glacier fed by five others which brought to it the tribute of their ice; a host of small glaciers fall into the vast glacier of Bionnassay; three glaciers pour themselves into that of the Miage in the neighbourhood of Courmayeur, and it is the same with nearly all others. The observer is therefore forced to conclude that the lower glaciers are solid rivers which take their origin in the glacial regions, and which descend into the temperate regions to change into liquid rivers. If, as we have seen in the preceding chapter, the formation of ice is considerable over the whole extent of the summits that surround Mont Blanc, the channels by which that mountain disburdens itself are also very numerous. The block of Mont Blanc alone is surrounded by fourteen stream glaciers, which are themselves fed by a much more considerable number of glaciers of the second order. Since the whole range of the Swiss Alps usually rises above the line of melting, it is covered with perpetual snow, and sustains glaciers in every direction; more than four hundred of them are reckoned from Mont Blanc to the Tyrol.

Le même auteur a vu dans la vallée de Ferret un glacier alimenté par cinq glaciers qui lui apportaient le tribut de leurs glaces; une foule de petits glaciers tombent dans le vaste glacier de Bionnassay; trois glaciers se versent dans celui du Miage aux environs de Cormayeur, et il en est ainsi de presque tous les autres. C'est donc pour l'observateur une nécessité de conclure que les glaciers inférieurs sont des fleuves solides qui prennent leur source dans les régions glaciales, et qui viennent dans les régions tempérées se changer en fleuves liquides. Si, comme nous l'avons vu dans le chapitre précédent, la formation des glaces est considérable sur toute l'étendue des sommités qui entourent le Mont-Blanc, les canaux par lesquels il se décharge sont aussi très-nombreux. Le seul massif du Mont-Blanc est entouré de 14 glaciers d'écoulement, qui sont eux-mêmes alimentés par un nombre bien plus considérable de glaciers du second ordre. Comme toute la crête des Alpes suisses dépasse ordinairement la ligne de fusion, elle se trouve couverte de neiges perpétuelles, et sur tous les points elle entretient des glaciers; on en compte plus de quatre cents depuis le Mont-Blanc jusque dans le Tyrol.

CHAPTER VIII.

OF THE MOTION OF STREAM GLACIERS.

ALTHOUGH most authors who have spoken of the lower glaciers have sufficiently false notions as to their origin and their formation, all, nevertheless, agree that they have a movement of translation which makes them advance towards the base of the valleys; but, the moment they would instruct us as to the nature and quantity of these movements, they fall into vagueness, and often even into absurdity. In fact *there* lies, in my opinion, the true Gordian knot. The fact of motion exists, the progression of glaciers is demonstrated; but the mode of motion is entirely unknown. Perhaps with long observations, with experiments upon ice and snow carefully made, we shall succeed in grasping it; but we are still in want of these first elements.

Glaciers have two kinds of motion, the one instantaneous, and the other insensible. If in its course the

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CHAPITRE VIII.

DU MOUVEMENT DES GLACIERS D'ÉCOULEMENT.

Quoique la plupart des auteurs qui ont parlé des glaciers inférieurs aient sur leur origine et leur formation des idées assez fausses, tous cependant conviennent qu'il existe pour eux un mouvement de transport qui les fait avancer vers le fond des vallées; mais dès l'instant où ils veulent faire connaître la nature et la quantité de ces mouvements, ils tombent dans le vague et souvent même dans le ridicule. En effet, c'est là, selon moi, le véritable nœud gordien. Le fait du mouvement existe, la progression des glaciers est démontrée; mais le mode est entièrement inconnu. Peut-être avec de longues observations, des expériences bien faites sur la glace et la neige, viendra-t-on à bout de le saisir; mais ces premiers éléments nous manquent encore.

Il y a dans les glaciers deux espèces de mouvement, l'un instantané et l'autre insensible. Si dans son cours le glacier

glacier meets with a slope very steep, scarped, vertical, the ice then splits and falls in blocks separated from one another. Such a motion is described in the following passage of M. de Saussure: "All the lower part of this "lofty summit (le dôme de l'Aiguille) was covered with "glaciers excessively scarped which poured into that "of Bionnassay; at every instant enormous blocks of ice "detached themselves from this glacier which we beheld "fall and precipitate themselves with a terrible crash, and "resolve themselves into whirlwinds of dust, which "the air, driven off by the fall of the ice, raised like "clouds to an astonishing height."*

Its fall is not always so rapid; even then, however, we notice upon the surface of the glacier unequivocal indications of a sharp movement, of a disturbance: splits, namely, and violent disarrangement of the relative positions of the masses of ice. M. de Saussure thus describes a place where the Talêfre passes over a steep incline: "As the slope by which this glacier descends "is extremely steep, its blocks of ice press against each "other, rise on end, lift themselves up, and form arched

* *Voyage dans les Alpes*, tome 2, p. 475.

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rencontre une pente très-rapide, escarpée, verticale, alors la glace se fend, tombe par blocs séparés les uns des autres. Un mouvement semblable est décrit dans le passage suivant de M. de Saussure: "Tout le bas de cette haute cime (le dôme de l'Ai- "guille) était couvert de glaciers excessivement escarpés qui se "versaient dans celui de Bionnassay; à chaque instant il se "détachait de ce glacier des masses énormes de glace que nous "voyions tomber et se précipiter avec un fracas horrible, et se "résoudre en des tourbillons de poussière que l'air, refoulé par "la chute des glaces, soulevait comme des nuages à une hauteur "étonnante." *

Sa chute n'est pas toujours aussi rapide; alors pourtant on aperçoit sur la surface du glacier des signes non équivoques d'un mouvement brusque, d'une perturbation: ce sont des fentes, du bouleversement dans la disposition des masses de glaces. Voici comment M. de Saussure depeint un passage rapide du Talêfre: "Comme la pente par laquelle ce glacier descend est extrême- "ment rapide, ses glaçons se pressent mutuellement, se dressent,

* *Voyage dans les Alpes*, tome 2, p. 475.

"hollows, pyramids of different inclinations, which seem "ready to crush the foolhardy traveller who should dare "to approach them."*

When the slope becomes gentler, the sharp sudden movements are rarer; but nevertheless they still manifest themselves by sudden splittings, and by the advance of blocks of ice. The inhabitants of districts which are in the neighbourhood of glaciers give to these movements which are known to them the name of *glacier-growths*. A minister of Grindelwald, who witnessed it whilst crossing the glacier which is in the neighbourhood of that village, thus describes this movement: "Scarcely were we in our places," says he, "when the "singular phenomenon called *glacier-growth* made its "presence known by a frightful noise; everything around "us appeared to move of itself—guns, alpenstocks, "game-bags. Rocks, apparently solidly fixed in the "ice, began to detach themselves and to dash against "each other; crevasses ten and twenty feet wide opened "before our eyes with a fearful crash; others, suddenly "closing, drove to a great height the water which they

* *Voyage dans les Alpes*, tome 2, page 24.

"se relèvent et forment des fours, des pyramides diversement "inclinées, qui semblent prêtes à écraser le voyageur téméraire "qui oserait s'en approcher." *

Quand la pente est radoucie, les mouvements brusques sont plus rares; mais pourtant ils se manifestent encore par des fentes subites et des avancements de blocs de glace. Les habitants des pays qui avoisinent les glaciers donnent à ces mouvements qui leur sont connus le nom de *crue de glacier*. Voici comment décrit ce mouvement un ministre de Grindelwald, qui en a été témoin en traversant le glacier qui est aux environs de ce village: "A peine étions-nous placés, dit-il, que "le singulier phénomène appelé *crue de glacier* se manifesta par "un bruit affreux; tout autour de nous paraissait se mouvoir de "soi-même: fusils, bâtons, carnassières. Des rocs en apparence "solidement établis dans la glace, commencèrent à se détacher "et à s'entrechoquer; des crevasses de 10 et de 20 pieds de "largeur s'ouvrirent à nos yeux avec un fracas épouvantable; "d'autres se fermant tout-à-coup, lancèrent à une grande

* *Voyage dans les Alpes*, tome 2, p. 24.

"contained. The whole mass of the glacier thus "suddenly agitated moved forward some paces; but "all soon returned to rest and to a profound silence, "scarcely broken by the whistling of the marmots."* Cutting out from this description the poetry which displays the rocks *dashing against each other*, we find the general fact of a sharp movement produced, to all appearance, by the advance of a portion of the glacier. We should know more about it if the witnesses of this scene had confined themselves to a scientific description.

M. Venetz reports that a glacier of the Vallée d'Hérens "advanced with a noise like that of thunder, making at once strides more than ten feet long." Without taking literally these descriptions, which carry with them marks of exaggeration, we may believe in the movements that called them forth. Let us now pass to the insensible movements.

Nothing seems to me more clearly demonstrated than the progressive motion of glaciers towards the bottom of the valley, and nothing at the same time

* Quoted from Malte Brun's *Geography*, vol. vii, page 101.

"hauteur l'eau qu'elles contenaient. La masse entière du glacier "si agitée tout-à-coup, s'était avancée de quelques pas; mais "tout rentra bientôt dans un repos et un silence profond, à "peine interrompu par le sifflement des marmottes."* En retranchant de cette description la poésie, qui montre les rochers *s'entrechoquant*, on y découvre la généralité d'un mouvement brusque produit, selon toute apparence, par l'avancement d'une partie du glacier. Nous en saurions davantage si les témoins de cette scène s'en étaient tenus à une description scientifique.

M. Venetz rapporte qu'un glacier de la vallée d'Hérens "avançait avec un bruit semblable à celui du tonnerre, faisant "à la fois des pas de plus de dix pieds de longueur." Sans prendre à la lettre ces descriptions qui portent avec elles des caractères d'exagération, on peut croire aux mouvements qui les ont motivées. Passons maintenant aux mouvements insensibles.

Rien ne me paraît plus clairement démontré que le mouvement progressif des glaciers vers le bas de la vallée, et rien en

* Cité d'après la *Géographie de Maltebrun*, volume 7, page 101.

seems to me more difficult to conceive than the manner in which this movement is executed—a movement so slow, so unequal, carried out on slopes of different inclination, on ground studded with irregularities, and in channels whose width varies at every moment. This is in my opinion the least explicable of the phenomena of glaciers. Does it advance in a mass like a block of marble on an inclined plane? Does it advance in broken bits like the stones which come down one after another in mountain gullies? Does it sink down upon itself to flow along the slopes, as lava would do, at once ductile and liquid? Do the portions which detach themselves at the edges of steep slopes suffice to impress motion upon those which repose upon a horizontal surface? I know not. Perhaps again we might say that in times of great cold, the water which fills the numerous transverse crevasses of the glacier, becoming frozen, receives its accustomed increment of volume, gives a push to its containing walls, and thus produces a motion towards the bottom of the channel in which it flows.

Let us turn our atttention to the portion of the Glacier des Bois which borders upon the Mont Envers.

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même temps ne me semble plus difficile à concevoir que la manière dont s'exécute ce mouvement si lent, si inégal, qui s'exécute sur des pentes différentes, sur un sol garni d'aspérités, et dans des canaux dont la largeur varie à chaque instant. C'est là, selon moi, le phénomène le moins explicable des glaciers. Marche-t-il ensemble comme un bloc de marbre sur un plan incliné? . . . Avance-t-il par parties brisées comme les cailloux qui se suivent dans les couloirs des montagnes? . . . S'affaisse-t-il sur lui-même pour couler le long des pentes, comme le ferait une lave à la fois ductile et liquide? . . . Les parties qui se détachent vers les pentes rapides suffisent-elles à imprimer du mouvement à celles qui reposent sur une surface horizontale? Je l'ignore. Peut-être encore pourrait-on dire que dans les grands froids l'eau qui remplit les nombreuses crevasses transversales du glacier venant à se congeler, prend son accroissement de volume ordinaire, pousse les parois qui la contiennent, et produit ainsi un mouvement vers le bas du canal d'écoulement.

Portons nos regards sur la partie du glacier des Bois qui

There it presents the appearance of a sea of ice whose agitated surface is in a nearly horizontal plane. This mass, extended, deep, compact, rigid, which is in contact with immovable banks that now widen, now contract, is nevertheless in motion. No breaking here; for the crevasses which we meet with there are not splits like those of which we have spoken above; we shall see elsewhere their origin, which is not due to the movement of the glacier. Nevertheless it advances there just as in the parts where the slope is more rapid. I have attempted to estimate the amount of its motion; but I have only succeded in collecting somewhat vague data. I questioned my guides as to the position of an enormous rock which is at the edge of the glacier, but still upon the ice, and therefore subjected to its movement. The guides showed me the place where it was the year before, and that where it was three, four, and five years ago; nay more, they showed me the place where it will be found in one year, in two years, and so on, so convinced are they of the regularity of this movement. At the same time their statements did not always exactly agree, and their indications of

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avoisine le Mont-Envers. Là il offre l'aspect d'une mer de glace dont la surface agitée serait dans un plan à peu près horizontal. Cette masse étendue, profonde, compacte, rigide, qui touche à des bords inébranlables, qui tantôt s'élargissent, tantôt se resserrent, est cependant en mouvement. Ici point de rupture, car les crevasses que l'on y rencontre ne sont pas des fentes comme celles dont nous avons parlé plus haut: nous verrons ailleurs leur origine, qui n'est pas due au mouvement du glacier. Cependant il avance là tout comme dans les parties où la pente est plus rapide, J'ai cherché à apprécier la quantité de son mouvement; mais je n'ai pu recueillir que des données un pen vagues. J'ai interrogé mes guides sur la position d'un énorme rocher qui est au bord du glacier, mais encore sur la glace et par conséquent soumis à son mouvement. Les guides m'ont montré l'endroit où il était l'année précédente, et celui où il était il y a trois, quatre et cinq ans; bien plus, ils m'ont montré l'endroit où il se trouvera dans un an, deax ans, etc., tant ils croient être certains de la régularité de ce mouvement. Cependant leurs rapports n'étaient pas toujours précisément

time and distances are always wanting in that precision of measurement and amount without which, in the physical sciences, we can but grope our way in the dark. Reducing these different elements of estimation to a mean, I found that the total advance must be about forty feet in a year. On my last journey I obtained the more certain information which I have set down in the last chapter; and the enormous difference which is shown between the two results arises from the fact that the last observations were made in the middle of the stream glacier, which advances with greater rapidity, whilst the first were made upon the edge, where the ice is held back by the friction of the walls of rock. Ebel thinks that the motion of glaciers is in general only from twelve to twenty-five feet a year; but it is easy to understand that it is impossible to obtain a general measure, and that there must be one for each glacier. The nature of the slope, the number of variations to which it is subjected, the depth of the ice, the width of its channel, the form of its banks, and a thousand other circumstances must make a difference in the rapidity with which the ice moves, and these circum-

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d'accord, et leurs indications de temps et de distances manquent toujours de cette précision de mesure et de quantité sans laquelle on est obligé de marcher à tâtons dans les sciences physiques. En réduisant ces différentes indications à une moyenne, je trouvai que l'avancement total devait être d'environ 40 pieds par année. Dans mon dernier voyage j'ai obtenu des renseignements plus certains que j'ai consignés dans le chapitre précédent, et l'énorme différence qui se trouve entre les deux résultats provient de ce que les dernières observations ont été faites au milieu du glacier d'écoulement, qui marche avec plus de rapidité, tandis que les premières ont été faites sur le bord, où la glace est retenue par le frottement des parrois rocheuses. Ebel pense que le mouvement des glaciers n'est en général que de 12 à 25 pieds par année; mais il est facile de comprendre qu'il est impossible d'obtenir une mesure générale, qu'il doit y en avoir une pour chaque glacier. La nature de la pente, le nombre des variations auxquelles elle est soumise, la profondeur des glaces, la largeur du couloir, la forme de ses bords, et mille autres circonstances doivent faire varier la vitesse des glaces,

stances cannot be absolutely the same everywhere. Nay more, it is not even easy to obtain this velocity for a single glacier, even with continuous observations; and for this reason: In the parts of the glacier where the slope is more rapid, the layer of ice is thinner, its velocity is greater; in those where the slope is almost *nil*, the ice swells and accumulates; the mass in motion being double, treble, &c., the velocity is but a half, a third, &c. Two observers, who should start from two points so wide apart, would each draw false conclusions.

Nor is this all—there is between the Glacier des Bois and a river a resemblance so complete that it is impossible to find in the glacier a circumstance which does not exist in the river. In currents of water the velocity is not uniform throughout their width nor throughout their depth; the friction of the bottom, that of the sides, the action of obstacles cause a variation in the velocity which is undiminished only towards the middle of the surface. Now, the mere inspection of the glacier is sufficient to prove that the velocity of the centre is greater than that of the sides. The whole

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et ces circonstances ne sauraient être absolument les mêmes partout. Bien plus, il n'est pas même facile d'obtenir cette vitesse pour un seul glacier, même avec des observations suivies; en voici la raison. Dans les endroits du glacier où la pente est plus rapide, la couche de glace est plus mince, sa vitesse est plus grande; dans ceux où la pente est presque nulle, les glaces se renflent, s'accumulent; la masse en mouvement étant double, triple, etc., la vitesse n'est que de la moitié, du tiers, etc. Deux observateurs qui partiraient de ces deux points si différents, tireraient l'un et l'autre des conséquences fausses.

Ce n'est pas tout, il y a entre le glacier des Bois et un fleuve une ressemblance tellement complète qu'il est impossible de trouver dans celui-ci une circonstance qui ne soit pas dans l'autre. Dans les courants d'eau, la vitesse n'est pas uniforme dans toute la largeur ni dans toute la profondeur; le frottement du fond, celui des bords, l'action des obstacles font varier cette vitesse, qui n'est entière que vers le milieu de la surface. Or, la seule inspection du glacier suffit pour prouver que la vitesse du milieu est plus grande que celles des rives. La

surface is cut by crevasses, which are in general transverse to its direction. If the motion were the same throughout the mass these crevasses which cut the surface in parallel drifts would form a straight line which would be always nearly perpendicular to the two banks; but this is not so; the general line is a curve whose convexity advances towards the bottom of the valley—a fact which can only be attributed to the greater velocity of the ice at this point.

M. de la Béche relates that a ladder which had been left by M. de Saussure on the Col du Géant in 1787 was found in 1830 opposite to the Aiguille du Moine, —three leagues lower down. Following the movement of the ice, this ladder must have advanced about 200 toises a year. M. Bozet, in his *Cours de Géologie*, says that a block of rock on the Glacier des Bois advanced only 183 metres in a year. To be correct, it would be necessary to discover the mean velocity—which is the real difficulty. Under the impossibility of arriving at it, I content myself with giving that which, to the best of my judgment, I found at a point where the slope is very much toned down.

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surface entière est coupée par des crevasses qui sont en général transversales à sa direction. Si le mouvement était le même dans toute la masse, ces crevasses qui coupent la surface en ondées parallèles formeraient une ligne droite qui serait toujours à peu près perpendiculaire aux deux rives; mais il n'en est point ainsi; la ligne générale est une courbe dont la convexité s'avance vers le bas de la vallée, ce qui ne peut être attribué qu'à l'excès de vitesse que les glaces ont sur ce point.

M. de la Béche raconte qu'une échelle qui avait été laissée par M. de Saussure sur le col du Géant en 1787, a été trouvée en 1830 vis-à-vis le pic du Moine, qui se trouve trois lieues plus bas. En suivant le mouvement des glaces, cette échelle aurait avancé d'environ deux cents toises par année. M. Bozet, dans son Cours de Géologie, dit qu'un bloc de rocher du glacier des Bois ne s'est avancé que de cent quatre-vingt-trois mètres dans une année. Pour être vrai, il faudrait découvrir la vitesse moyenne, c'est là le difficile; dans l'impossibilité d'y parvenir, je me contente de donner celle que j'ai cru trouver vers un point où la pente est très-radoucie..

I cannot refrain from here venturing upon a suggestion which has no other foundation than analogy of position —but as it may be of great importance in helping to explain the circulation of water round the globe, I offer it to physicists, without myself reposing entire faith in it. It is as follows—

The learned observations of M. de Humboldt, those of Captains Garry, Franklin, and Back, have furnished the means of establishing the ratio in which temperature is lowered in proportion as we rise towards the poles and in a direction perpendicular to the horizon. Thus the isothermal line, which marks the commencement of perpetual snow, abuts in the one direction upon the seventy-fourth degree of northern latitude, and in the other upon a height of 8,000 feet up Mont Blanc; so that the summit of this mountain must have somewhere about the temperature of the glacial zone near the poles of the earth.

But must not this identity of position produce identity of effect? And might not the poles of the earth be also considered as two immense glaciers incessantly maintained by the condensation of the vapours which flow in towards them by the upper part

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Je ne puis m'empêcher de hasarder ici une idée qui n'a d'autre fondement que l'analogie de position; mais comme elle peut être d'une grande importance pour l'intelligence de la circulation des eaux autour du globe, je la livre aux savants, sans y ajouter moi-même une foi entière. La voici:

Les savantes observations de M. de Humboldt, celles des capitaines Garry, Franklin et Back, ont fourni les moyens d'établir les rapports d'après lesquels s'abaisse la température à mesure qu'on s'élève vers les pôles et dans la perpendiculaire à l'horizon. Ainsi la ligne isotherme qui marque le commencement des neiges perpétuelles aboutit d'un côté vers le 74^{me} degré de latitude boréale et de l'autre vers le 8,000^{me} pied de la hauteur du Mont Blanc, de sorte que le sommet de cette montagne doit avoir à peu près la température de la zone glaciale près des pôles de la terre.

Mais cette identité de position ne doit-elle pas produire l'identité des effets? Et les pôles de la terre ne pourraient-ils pas aussi être considérés comme deux immenses glaciers sans cesse entretenus par la condensation des vapeurs qui affluent

of the atmosphere, and which discharge their ice into the surrounding seas? In this case, the pressure resulting from the motion of rotation, which has been capable of producing the flattening of the poles, would replace the action of weight, which is sufficient to make the ice flow over the inclined planes of the mountains; and the masses of floating ice, which are often met with in the polar seas, would answer to the stream glaciers of our Alps—they would, at any rate, be rivers of ice setting forth to go and be melted in the temperate zones. We should find therein one more example of that law of circulation so often set to work in the operations of nature.

CHAPTER IX.

OF ROCK-TRAINS.

When we examine a glacier from an elevated point, we see towards the middle one, two, and sometimes

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vers eux par la partie supérieure de l'atmosphère et qui se déchargent de leurs glaces dans les mers environnantes. Dans ce cas, la pression résultant du mouvement de rotation qui a pu produire l'applatissement des pôles, remplacerait l'action de la pesanteur, qui suffit pour faire couler la glace sur les plans inclinés des montagnes; et les masses de glace flottante que l'on rencontre souvent dans les mers polaires, seraient comme les glaciers d'écoulement de nos Alpes. Ce serait toujours des fleuves de glace partant pour aller se fondre dans les zones tempérées. Nous retrouverions encore là un exemple de cette loi de la circulation, si souvent mise en œuvre dans les opérations de la nature.

CHAPITRE IX.

DES TRAINÉES ROCHEUSES.

Quand on examine un glacier d'un point élevé, on voit vers le milieu une, deux et quelquefois trois ou quatre traces de

three or four tracks of sand, of earth, and of blocks of rock which extend throughout its length, following lines parallel to the sides. These selvages, as it were, of a gray-blackish colour which contrast with the ice, astonish all travellers. I shall give them the name of *rock-trains,* which seems to me to characterize them well enough. We may ask ourselves, with respect to these roads of stone, several questions to which none but false, or at least insufficient, answers have been given. *First,* Whence come these rocks? *Secondly,* Why are they at the surface rather than in the interior of the ice? *Thirdly,* Why towards the middle rather than towards the sides? *Fourthly,* Why divided into several trains? *Fifthly,* Why is the ice higher beneath every rock? I will answer each of these questions, the solutions of which appear to me easy.

First. The glaciers often pass at the feet of laminated rocks of which they receive the *débris;* on the other hand avalanches scarcely ever happen without bringing with them earth and detached blocks; lastly, the ice which falls from precipitous summits brings its quota of them too; it is not, therefore, surprising that

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sable, de terre et de blocs de rochers qui s'étendent sur toute sa longueur, en suivant des lignes parallèles aux bords. Ces espèces de lisières de couleur gris-noirâtre qui contrastent avec la glace, étonnent tous les voyageurs. Je leur donnerai le nom de *Traînées Rocheuses,* qui me paraît assez bien les caractériser. On peut se faire, relativement à ces voies pierreuses, plusieurs questions auxquelles on n'a donné que des solutions fausses ou du moins insuffisantes. 1° D'où viennent ces rochers? 2° Pourquoi sont-ils à la surface plutôt qu'à l'interieur des glaces? 3° Pourquoi vers le milieu plus que vers les bords? 4 Pourquoi divisés en plusieurs traînées? 5° Pourquoi la glace est-elle plus élevée sous chaque rocher? Je vais répondre à chacune de ces questions, dont les solutions me paraissent faciles.

1° Les glaciers passent souvent aux pieds des rochers feuilletés dont ils reçoivent les débris; d'un autre côté, les avalanches n'arrivent guère sans entraîner avec elles des terres et des blocs détachés; enfin, les glaces qui tombent des sommets escarpés en entraînent aussi: il n'est donc pas étonnant que le

the river of ice, like all torrents, should carry off the *débris* of the mountain from which it descends.

Secondly. Why are they on the surface? There is amongst the mountain inhabitants of the Alps a general prejudice, which many travellers and naturalists have shared—viz., that glaciers cast up on their surface all foreign bodies which are in their interior. A guide, in pointing out this fact to me, made use of an axiom which comprehended the whole belief of the country on this subject. *The glacier*, said he to me, *keeps nothing impure.*

What has given rise to this popular axiom, that the glacier keeps nothing impure (which means nothing foreign to its substance), may be as follows:—On attentively observing the texture of the ice, we perceive that the foreign particles which it contains have not entered into combination with its substance, but that they are gathered together, and that they have formed nests, nodules, little heaps inclosed in hollows left by the ice. The very air has been repelled from intimate combination, and is collected together in little globules more or less elliptical, which give to the ice as a whole

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fleuve de glace emporte, comme tous les torrents, les débris des montagnes d'où il descend.

2° Pourquoi sont-ils à la surface? Il y a parmi les montagnards des Alpes un préjugé général qu'ont partagé beaucoup de voyageurs et de naturalistes, c'est que les glaciers rejètent à leur surface tous les corps étrangers qui sont dans leur intérieur. Un guide, en m'endiquant ce fait, se servait d'un axiome qui contenait sur ce sujet toute la croyance du pays: *Le glacier*, me disait-il, *ne garde rien d'impur.*

Voici ce qui a pu donner lieu à cet axiome populaire, que le glacier ne garde rien d'impur, ce qui signifie rien d'étranger à sa substance: en observant attentivement la contexture de la glace, on s'aperçoit que les parties étrangères qu'elle contient ne sont point entrées en combinaison avec sa substance, mais qu'elles se sont réunies entre elles, et qu'elles ont formé des nids, des nodules, de petits amas renfermés dans un vide laissé par la glace. L'air lui-même a été repoussé de la combinaison intime, et s'est réuni en petits globules plus ou moins elliptiques, qui donnent à l'ensemble de la glace cette forme bulleuse

that bubbled appearance of which I have spoken elsewhere. The little heaps of sand are very frequent in the ice. This is but the repetition of a phenomenon which is met with in every kind of crystallization. At the moment when crystallization begins, particles of identical constitution, being free to move in the medium which serves them as a vehicle, seek one another, draw nearer and nearer to one another, and leave the foreign particles in their isolation. These in their turn seek their congeners, and form other spherulæ which, inferior in numbers, remain imprisoned in the more powerful substance. This general law of assimilation, which is as the soul or the will of nature, obtains throughout, but in particular in mineralogy. It is thence that arise the formation of *nuclei* in rocks, the crystalline spherulæ of all the granitoids, crystals on their *gangues*, *géodes* in the rocks in which they are encrusted, amygdaloid aggregations, the veins of ribboned schists, the marbled appearance of a great number of substances, etc., etc. But we must be careful to observe that the moment that solidity is established between the particles, each keeps its place for

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dont j'ai parlé ailleurs. Les petits amas de sable sont fort fréquents dans les glaces. Ce n'est ici que la répétition d'un phénomène qui se rencontre dans tous les genres de cristalisation. Au moment oú la cristalisation commence, les parties identiques libres de se mouvoir dans le milieu qui leur sert de véhicule, se cherchent, s'unissent de proche en proche et laissent les parties étrangères dans leur isolement. Celles-ci à leur tour cherchent leurs analogues et forment d'autres sphérules qui, moins nombreuses, restent emprisonnées dans la substance la plus puissante. Cette loi générale de l'assimilation, qui est comme l'ame ou la volonté de la nature, s'observe partout, mais en particulier dans la minéralogie. C'est de là que viennent la formation des *nœuds* dans les rochers, les sphérules cristalines de tous les granitoïdes, les cristaux sur leurs gangues, les géodes dans les rochers où elles sont empâtées, les agrégations amigdaloïdes, les veines des schistes rubannés, les apparences jaspées d'un grand nombre de substances, etc., etc. Mais il faut bien observer que dès l'instant où la solidité est établie entre les parties, chacune garde éternellement sa place jusqu'à

ever until a power external to the system comes and destroys the integrity of the combination to give passage to foreign substances. Nothing therefore of what is contained in the interior of the ice can get out of it before the ice is melted to the spot where the foreign substance lies.

To return to the received prejudice. It is thought then that a rock which has rolled into a deep crevasse rises up again little by little towards the surface—that it is vomited up by the glacier. This mysterious force, which brings up again from below masses so considerable, has much occupied the attention of physicists—a theory ingenious enough had even been invented to explain it; but, as often happens with the constructors of theories, the facts had been arranged to suit the theory instead of basing the theory upon the facts.

It can be given in two words. The rocks are in the crevasses; the vapour which is condensed on their walls, and the rain water which falls on them, flow down to the lower part of the block in contact with the ice; there this water is frozen; by this very operation its volume is augmented, and by this means it lifts up the

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ce qu'une puissance venue d'en dehors du système, détruise l'ensemble de la combinaison pour donner un passage aux substances étrangères. Rien donc de ce qui est contenu dans l'intérieur des glaces ne peut en sortir avant que la glace ne soit fondue jusqu'à l'endroit où se trouve la substance étrangère.

Revenons au préjugé reçu. On pense donc qu'un rocher qui a roulé dans une crevasse profonde, remonte peu à peu vers la surface; qu'il est revomi par le glacier Cette force mystérieuse qui reportait une masse aussi considérable de bas en haut, a beaucoup occupé les physiciens; on avait même imaginé pour l'expliquer une théorie assez ingénieuse; mais, comme cela se pratique souvent parmi les faiseurs de théorie, on avait rangé les faits pour le théorie au lieu de baser la théorie sur les faits.

La voici en deux mots: Les rochers sont dans les crevasses; la vapeur qui se condense sur leurs parrois, l'eau de pluie qui tombe sur eux coulent jusqu'à la partie inférieure du bloc en contact avec la glace; là cette eau se congèle; par là même elle augmente de volume, et par ce moyen soulève le bloc d'une

block by an amount in proportion to the quantity of water frozen. By constant repetition, this movement at length bears the rock to the surface of the glacier.

Without stopping for needless refutations, let us begin by giving the facts which have led to error. Stones are more numerous on the surface, because those in the interior not being visible, we cannot make a comparison; because all those which fall on the glacier throughout its course remain there; and lastly, because a portion of those which are at first covered with ice end by finding themselves entirely on the outside; and it is this last circumstance which has led to erroneous conclusions; it is the one which it is important to explain.

If we examine a rock still buried in the ice and which shows itself on the surface at one point only, we observe that this visible point becomes larger and larger. At the end of a year the progress is sensible, and there arrives at last a period when the whole rock is visible. It is inferred that the ice has rejected it. It would have been just as easy to say that the ice having diminished above and then around it, the rock is found on the surface because this surface, whose nature it is to

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quantité proportionnée à la quantité d'eau congelée. A force de se répéter, ce mouvement porte enfin le rocher à la surface du glacier.

Sans nous arrêter à des réfutations inutiles, commençons par donner les faits qui ont pu induire en erreur. Les cailloux sont plus nombreux à la surface, parce que ceux de l'intérieur n'étant pas visibles, on ne peut faire de comparaison; parce que tous ceux qui tombent sur le glacier pendant tout son trajet, y restent; et enfin, parce qu'une partie de ceux qui sont d'abord couverts de glace, finissent par se trouver entièrement au dehors; et c'est cette dernière circonstance qui a pu induire en erreur; c'est celle qu'il importe d'expliquer.

Si l'on examine un rocher encore enseveli dans la glace et qui ne se montre à la surface que par un point, on observe que ce point visible devient de plus en plus grand. Au bout d'une année, le progrès est sensible, et enfin il arrive une époque où tout le rocher est visible; on en conclut que la glace l'a repoussé; il eût été tout aussi facile de dire que la glace ayant diminué au-dessus et ensuite autour de lui, le rocher s'est trouvé à la surface, parce que cette surface dont la nature

change, must have sunk in proportion as melting has taken place.

In fact, as soon as the ice has passed the line which separates the region of vegetation from that of ice, it begins to melt, and the quantity of this melting increases proportionately to its descent; so that the quantity of ice supplied by the current is so much the less as the place of measurement is lower down, until we arrive at the point of total destruction. It must follow necessarily that a rock, which towards the upper part of the glacier was hidden beneath a certain thickness of ice, must be entirely visible when it has passed through a certain space along with the mass which bears it on. Did this explanation need demonstration, it could be given by the facts I am going to mention. In the middle of the *rock-trains* there are blocks which are not on the surface but raised above it on pedestals of ice. M. de Saussure had observed this fact; it is thus that he speaks of it: "The ice under these ridges (this is the name he gives "to the *rock-trains*) is much higher than in their "intervals, because the *débris* accumulated upon them "preserves it from the action of the sun and prevents it

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est changeante, a dû s'abaisser à mesure que la fusion s'est opérée.

En effet, dès que les glaces ont dépassé cette ligne qui sépare la région végétale de la région glacée, elles commencent à fondre, et la quantité de cette fusion s'accroît à raison de leur abaissement; de sorte que la quantité de glace fournie par le courant est d'autant moindre qu'on la mesure plus bas, jusqu'à ce que l'on arrive au point de la destruction totale. Il doit s'en suivre nécessairement qu'un rocher qui, vers le haut du glacier, était caché au-dessous d'une certaine épaisseur de glace, doit se trouver entièrement visible quand il a fait avec la masse qui l'entraîne un certain trajet. Si cette explication avait besoin d'être démontrée, on pourrait le faire par les faits que je vais indiquer. Au milieu des *traînées rocheuses*, il y a des blocs qui ne sont pas à la surface, mais élevés au-dessus d'elle sur des piédestaux de glace. M. de Saussure avait observé ce fait; voici comment il en parle: "La glace sous ces arêtes (il appelle "ainsi les *traînées rocheuses*) est beaucoup plus élevée que "dans leurs intervalles, parce que ces débris accumulés sur "elle, la préservent de l'action du soleil et l'empêchent de se

"from being reduced to water or vapour. We even see "in many places great fragments of rock upheld at a "height of 4 or 5 feet above the level of the glaciers by "pedestals of snow or of ice which they have prevented "from being melted."

I find the same phenomenon on the glacier of the Talêfre. "We halted under the shade of an enormous "block of granite which was upheld at a height of "several feet above the glacier by a pedestal of living "ice of which it had prevented the melting."*

Unless we were to say that the glaciers have such a horror of rocks that they raise them even several feet above their surface, we must be content to say that it is the level of the glacier that has been lowered by the process of melting, which appears to be pretty considerable even at the height of the Talêfre, inasmuch as the fragment of granite remained raised several feet above the surface of the glacier.

Thirdly. Why towards the middle rather than towards the sides? M. de Saussure has attempted to account for this phenomenon; but what he says is far

* *Voyage dans les Alpes*, tome 2, pages 23 and 27.

"réduire en eau ou en vapeur. On voit même en bien des "endroits de grands fragments de rocher soutenus à 4 ou 5 pieds "au-dessus du niveau du glacier, par des piédestaux de neige ou "de glace qu'ils ont empêché de fondre."

Je trouve le même phénomène sur le glacier du Talêfre. "Nous fîmes halte à l'ombre d'un bloc énorme de granite qui "était soutenu à plusieurs pieds d'élévation au-dessus du "glacier par un piédestal de glace vive, dont il avait empêché "la fusion."*

A moins que l'on ne voulût dire que les glaciers ont une telle horreur pour les rochers qu'ils les élèvent même de plusieurs pieds au-dessus de leur surface, il faudra bien consentir à dire que c'est le niveau du glacier qui s'est abaissé par la fusion, qui paraît assez considérable même à la hauteur du Talêfre, puisque le fragment de granite est resté élevé de plusieurs pieds au-dessus de la surface du glacier.

3° Pourquoi vers le milieu plutôt que vers les bords? M. de Saussure a voulu rendre raison de ce phénomène; mais ce qu'il

* *Voyage dans les Alpes*, tome 2, page 23 et 27.

from being satisfactory to a mind determined beforehand not to be content with an appearance of light. I have sought another solution of the problem; I thought I had found it in the passage of glaciers through contracted gorges where the streams of ice, brought into one, carried towards a single point of small extent the fragments which they bear, and which, after such passage, remained in the same relative position; but on submitting this cause to a severe criticism, I saw that it could not stand the test, and I leave to others the task of clearing up this mystery.

Nevertheless, I wish to add a cause which is not destitute of all probability. As we shall see in the following chapter, the surface of glaciers is in general convex, and the curve which bounds them increases considerably as we come near the edges. Is it not probable that the blocks of rock which are the nearest to the banks have slid little by little, following the lateral slope, and have come to increase or form those *moraines* which almost constantly fringe the glaciers? This is all the more probable, inasmuch as the *rock-trains* repose, towards the middle of the glaciers, on a

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dit est loin de pouvoir satisfaire un esprit décidé d'avance à ne pas se contenter d'une apparence de lumière. J'ai cherché une autre solution du problème; j'avais cru l'avoir trouvée dans le passage des glaciers par des gorges resserrées où les glaces réunies portaient vers un point peu étendu les fragments qu'ils entraînent, et qui après le passage demeuraient dans cette position respective; mais en soumettant cette cause à une sévère critique, j'ai vu qu'elle ne pouvait en supporter l'épreuve, et j'ai laissé à d'autres le soin d'éclaircir ce mystère.

Cependant je veux ajouter une cause qui n'est pas dépourvue de toute probabilité. Comme nous le verrons dans le chapitre suivant, la surface des glaciers est en général convexe, et la courbe qui les termine augmente considérablement en arrivant vers les bords. N'est-il pas probable que les blocs de rochers qui sont le plus rapprochés des rives ont glissé peu à peu en suivant la pente latérale, et sont venus accroître ou former ces *moraines* qui bordent presque constamment les glaciers? Ceci est d'autant plus vraisemblable, que les *traînées rocheuses*

part more elevated, and, in general, more unbroken than the rest of the surface.

Fourthly. Why several distinct and separate *trains?* The answer is easy. When two rivers unite, their waters do not mingle at once; they move on abreast in the same bed, and if their colour is different, they may still be recognized at more than half a league from their confluence. *A fortiori* it is the same with rivers of ice; they reach the same bed, each bearing its *rock-train*, and as their solid waves cannot intermingle, the trains take each its course in parallel lines down to the end of the glacier. There are on the Glacier des Bois three *rock-trains*, because it is, in fact, formed of three glaciers which come and unite themselves in one valley.

Fifthly. Why is the surface of the glacier higher underneath these *trains?* M. de Saussure gives a correct reason for the phenomenon—namely, that the ice, protected from the sun by the presence of earth and rocks, does not melt at this point as much as elsewhere. To that I will add a second, which I will work out at length by and by, when its power will be better understood. It is that these rocks protect the ice from

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restent vers le milieu des glaciers sur une partie plus élevée et en général plus unie que le reste de la surface.

4° Pourquoi plusieurs *traînées* distinctes et séparées? La réponse est facile. Quand deux fleuves se réunissent, leurs eaux ne se mêlent pas dès le premier moment; elles avancent de front dans le même lit, et si leur couleur est différente, on les reconnait encore à plus de demi-lieue du confluent A plus forte raison en est-il de même des fleuves de glace: ils arrivent dans le même lit chacun portant sa *traînée rocheuse*, et comme leurs flots solides ne peuvent se confondre, les traînées se suivent parallèlement jusqu'au bout du glacier. Il y a sur le glacier des Bois trois *traînées rocheuses*, parce qu'en effet il est formé de trois glaciers venus se réunir dans la même vallée

5° Pourquoi sous ces traînées la surface du glacier est-elle plus élevée? M. de Saussure en donne une raison vraie, c'est que la glace préservée du soleil par la présence de la terre et des rochers, ne fond pas sur ce point autant qu'ailleurs. A celle-là j'en ajouterai une seconde, que je développerai plus tard, et dont on comprendra mieux la puissance: c'est que ces rochers

the rain which causes it to melt much more rapidly than the sun would do.

CHAPTER X.

OF THE FORM OF STREAM GLACIERS.

I HAVE already observed that stream glaciers are rivers of solid water; all the phenomena of rivers are reproduced in them with a fidelity which would be sufficient to make us suspect the purposes they serve. They widen or contract according to the nature of the sides. The velocity of the waves is measured by the rapidity of the slope; the cavities and inequalities which are very probably to be found in the bottom of its bed are not reproduced at the surface, which preserves a uniform progress. The drifts of ice marked by transverse crevasses seem to come on in regular succession; but they appear to have more rapidity towards the middle, which gives to each wave the form of a semicircle whose

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garantissent la glace de la pluie qui la fait fondre bien plus rapidement que ne le ferait le soleil.

CHAPITRE X.

DE LA FORME DES GLACIERS D'ÉCOULEMENT.

Je l'ai déjà dit, les glaciers d'écoulement sont des fleuves d'eau solide; tous les phénomènes des fleuves s'y retracent avec une fidélité qui suffirait pour faire soupçonner leur usage: ils s'élargissent ou se rétrécissent selon la nature des bords. La vitesse des flots se mesure sur la rapidité de la pente; les cavités et les inégalités qui se trouvent bien probablement dans le fond du lit, ne se reproduisent point à la surface, qui conserve une marche uniforme. Les ondées de glace marquées par des crevasses transversales semblent se suivre; mais elles paraissent avoir plus de rapidité vers le milieu, ce qui donne à chaque ondée la forme d'un demi-cercle dont la convexité est

convexity is turned towards the bottom of the valley. The river follows a straight line or winds according to the direction of its banks. There are in the form of glaciers four principal characteristics which deserve our attention for a moment. They are—firstly, their swelling towards the middle; secondly, the crevasses which cover them; thirdly, wells; fourthly, drainage waters.

Of the Swelling of Ice Streams.

It must be remembered that my observations always refer to the Glacier des Bois, which is, so to speak, a classical glacier, by reason of its extent, its mass, its position and the aggregate of the phenomena which it presents. When we wish to cross it, we begin by mounting from the side to the middle or nearly so, and thence we descend again to the other bank, so that the surface of the glacier is hog-backed, and the waters which proceed from the melting of the ice distribute themselves and flow from the middle towards the two banks and not in the direction of the flow of the stream. The reason of this form is, as I believe, the much greater

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tournée vers le bas de la vallée. Le fleuve suit une ligne droite ou serpente selon la direction de ses rives. Il y a dans la forme des glaciers quatre choses principales qui méritent de nous arrêter un instant, ce sont 1° leur renflement vers le milieu, 2° les crevasses qui les couvrent, 3° les puits, 4° les eaux d'écoulement.

Du renflement des glaciers d'écoulement.

Il faut se rappeler que mes observations se rapportent toujours au glacier des Bois, qui est pour ainsi dire un glacier classique par son étendue, par sa masse, par sa position et par l'ensemble des phénomènes qu'il présente. Quand on veut le traverser, on commence par monter dès le bord jusqu'au milieu ou à peu près, et de là on redescend jusqu'à l'autre rive, de sorte que la surface du glacier est en dos-d'âne, et les eaux qui proviennent de la fonte des glaces se distribuent et coulent du milieu vers les deux rives et non pas dans le sens de la direction du fleuve. J'ai cru trouver la raison de cette forme

melting at the sides than towards the middle. I might point out as the original cause the reflection of the sun produced by the rocks along the shores; but if this cause is of any consequence in the production of the phenomenon under consideration, I think it not sufficiently appreciable, looking to the effects produced, to set it down as the only one. This increased melting is due, in my opinion, to the flow of water.

Several circumstances had proved to me that ice subjected in air to an elevated temperature resisted melting very much longer than when exposed to moisture or put into even very cold water. In order to obtain a little more precision, I made some experiments which fully confirmed me in this opinion. In the month of August, I took two cubes of ice, each weighing one pound. I put the first into a volume of water weighing nine pounds, and at a temperature of 57° Fahrenheit, and in the shade. I exposed the second in a wicker basket to a sun of $83\frac{3}{4}$° Fahrenheit. The first was entirely melted at the end of an hour and fifteen minutes, lowering the temperature of the water in which it was to 43°. The second passed six hours in

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dans la fusion bien plus grande sur les bords qu'elle ne l'est vers le milieu. Je pourrais indiquer comme première cause la réverbération du soleil produite par les rochers du rivage; mais si cette cause est pour quelque chose dans la production du phénomène qui nous occupe, je la crois trop peu sensible pour la placer seule vis-à-vis des effets produits. Cet accroissement de fusion est dû selon moi à l'écoulement des eaux.

Plusieurs circonstances m'avaient prouvé que la glace soumise, dans l'air, à une température élevée, résistait bien plus longtemps à la fusion que quand elle était exposée à l'humidité ou mise dans de l'eau même très-froide. J'ai fait, pour obtenir un peu plus de précision, quelques expériences qui m'ont pleinement confirmé dans cette opinion. Au mois d'août, j'ai pris deux cubes de glace, chacun du poids d'une livre. J'ai mis le premier dans un volume d'eau du poids de neuf livres, et à la température de + 11° Réaumur et à l'ombre. J'ai exposé le second dans un panier d'osier, à un soleil de + 23° Réaumur. Le premier a été entièrement fondu après une heure et 15 minutes, en abaissant la température de l'eau dans laquelle il était à + 5°. Le second a passé six heures au soleil, et ensuite

the sun, and then in a temperature of from 63½° to 66°, and was melted only at the end of 14 hours.

To discover the relation which exists between the power of water to effect the fusion of ice, and the power of the air to bring about the same result, I reasoned as follows :—

Firstly. The first bit of ice, which was melted in one hour and fifteen minutes, whilst reducing the water from 57° to 43°, may be supposed, without any considerable error, to have melted in a mean temperature of 50°.

To compare now the cube of ice exposed to the sun and air with that which was subjected to the water, I reduced to 50° the two temperatures to which it was exposed. Thus, let us grant in the process of first approximation, that the ice exposed to the sun in an atmosphere at 83¾° was melted no faster than if it had been in the shade in an atmosphere also raised to the temperature of 83¾°; six hours passed in an atmosphere at 83¾°are equivalent to 17 hours 15 minutes passed in an atmosphere at 50°; for it is evident that the periods necessary to melt the same quantity of ice are in the inverse ratio of the temperatures of the air in which the

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dans une température de + 14 à 15 degrés, et n'a été fondu qu'après 14 heures.

Voici comment j'ai raisonné pour découvrir le rapport qui existe entre le pouvoir de l'eau pour opérer la fusion de la glace, et le pouvoir de l'air pour obtenir le même résultat.

1° Le premier morceau de glace qui a fondu en une heure et 15 minutes en ramenant l'eau de + 11° à + 5°, peut être supposé, sans erreur trop considérable, avoir fondu dans une température moyenne de + 8°.

Pour comparer maintenant le cube de glace exposé au soleil et à l'air, à celui qui a été soumis à l'eau, j'ai réduit à + 8° les deux températures auxquelles il a été exposé. Ainsi admettons dans une première approximation que la glace exposée au soleil dans un air à + 23° n'ait pas fondu plus vite que si elle avait été à l'ombre dans un air aussi élevé à la température de + 23°; six heures passées dans un air à + 23° équivalent à 17 heures 15 minutes passées dans un air à + 8°; car il est évident que les temps nécessaires pour fondre une même quantité de glace sont en raison inverse des températures de l'air dans

ice is (the temperatures being measured from the freezing point, or 32°) we shall have, therefore, 18° : $51\frac{3}{4}$° :: 6 hours : x: whence x = 17 hours 15 minutes. For the same reason, the eight hours passed in an atmosphere at $63\frac{1}{2}$° are equivalent to 14 hours passed in an atmosphere at 50°; for we shall have, as above, 18° : $31\frac{1}{2}$° :: 8 hours : x : whence x = 14 hours.

Melting in the air at 50° would therefore have taken place in 17 hours 15 minutes + 14 hours = 31 hours 15 minutes, a period equal to 25 times 1 hour 15 minutes, that is to say, the time necessary for the melting of a quantity of ice in water at 50°.

This ratio of 25 to 1 is much below the truth; for, *First*, the mean temperature of the water must have been below 50°, because the water must have cooled at the beginning in a ratio much more rapid than at the end. (It would be greater still in the case of water in agitation or running); *Secondly*, the ice in the sun melted not only by the contact of the air, but also by the direct action of the solar rays. Now, these two causes concurred in diminishing the ratio we are in search of.

If, by way of an approximation, we suppose that the

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lequel cette glace se trouve: on aura donc: (+ 8° : + 14° [? 23°] : : 6 h. : x = 17 heures 15 minutes). Par la même raison, les huit heures passées dans un air à + 14°, équivalent à 14 heures passées dans un air à + 8°; car nous aurons comme tout à l'heure : (+ 8° : + 14° : : 8 h. : x = 14 heures).

La fusion dans l'air à + 8° aurait donc eu lieu dans 17 heures 15 minutes + 14 heures = 31 heures 15 minutes, temps qui égale 25 fois 1 h. 15 m., c'est-à-dire le temps nécessaire pour la fusion d'une quantité de glace dans de l'eau à + 8°.

Ce rapport de 25 à 1 est de beaucoup inférieur à la vérité; car, 1° la température moyenne de l'eau a dû être au-dessous de 8°, parce que l'eau a dû se refroidir au commencement dans un rapport beaucoup plus rapide qu'à la fin. (Il serait encore plus grand dans une eau agitée ou courante); 2° la glace au soleil fondait non-seulement par le contact de l'air, mais aussi par l'action directe des rayons solaires. Or, ces deux causes ont concouru pour diminuer le rapport que nous cherchons.

Si par une approximation on suppose que la glace, pendant

ice, during the six hours passed in the sun, melted as much by the direct action of the solar rays as by the contact of the air, the six hours passed in the sun would be equivalent no longer to 17 h. 15 m. but to twice that amount—viz., to 34 h. 15 m. passed in an atmosphere at 50°; we should have, therefore, 34 h. 30 m. + 14 h. = 48 h. 30 m. for the time necessary for a cube of one pound of ice placed in an atmosphere of 50° to arrive at complete melting, whilst in water it needed but 1 h. 15 m. to produce that result; the ratio of these two numbers would be 38·8 to 1, instead of 25, the figure arrived at just now.

Without wishing to claim for this experiment all the precision of which it is susceptible, it at any rate results from it that ice melts much more rapidly under the action of water than under that of the air; the same conclusion, moreover, might have been arrived at directly, from the enormous difference between their capacities for heat—for, with equal masses, that of water being 1, that of the air is only 0·2669.

The knowledge of this property of water is of great importance, and we shall see that it accounts for the greater part of the phenomena presented by glaciers.

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les 6 heurs passées au soleil, a fondu autant par l'action directe des rayons solaires que par le contact de l'air, les 6 heurs passées au soleil n'équivalent plus à 17 h. 15 m., mais au double, à 34 h. 30 m. passées dans un air à + 8°; on aurait donc 34 h. 30 m. + 14 h. = 48 h. 30 m. pour le temps nécessaire à un cube d'une livre de glace placé dans un air à + 8°, pour arriver à la fusion complète, tandis que dans l'eau il n'a fallu pour cela que 1 h. 15 m.; le rapport de ces deux nombres serait de 38,8 à 1, au lieu de 25 que nous avons trouvé tout à l'heure.

Sans vouloir donner à cette expérience une précision aussi grande qu'elle pourrait l'avoir, il en résulte du moins que la glace fond beaucoup plus vite sous l'action de l'eau que sous celle de l'air; c'est d'ailleurs ce qu'on aurait pu conclure directement de l'énorme différence de leur capacité pour le calorique; car, à masse égale, celle de l'eau étant 1, celle de l'air n'est que de 0,2669.

La connaissance de cette propriété de l'eau est très-importante, et l'on verra qu'elle rend compte de la plupart des

It is even susceptible of practical application. After the terrible inundation which ravaged the Vallée de Bagnes in the Valais, on the 16th June, 1818, the Government instituted researches on the most effectual means for preventing the recurrence of such a scourge. The problem was to destroy the accumulation of ice which prevented the water from flowing away. The engineer who was at the head of this undertaking employed no other expedient than that of directing the waters from above over the surface of the glacier, so as to diminish its mass by fusion. Whatever opposition M. Venetz encountered, I am of opinion that the method chosen by him is a perfectly rational one, since it is justified by the experiment I have just pointed out. I have not been able to learn whether his attempt has met with the success that he expected from it.

Let us now bring our experiment to bear upon the glaciers. The rain water, the water formed by the condensation of vapour, the water which proceeds from the melting of ice, arrive at the two edges of the glacier; but, as they start from the middle, their quantity will be greater in proportion as they approach

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phénomènes que présentent les glaciers. Elle est même susceptible d'applications utiles. Après la terrible débâcle qui ravagea la vallée de Bagnes en Valais le 16 juin 1818, le gouvernement fit rechercher les moyens les plus propres à prévenir le retour d'un tel fléau. Il fallait détruire des amas de glace qui arrêtaient l'écoulement des eaux. L'ingénieur qui présidait à cette entreprise, n'a pas employé d'autre moyen que celui de diriger les eaux supérieures sur la surface du glacier, afin d'en diminuer la masse par la fusion. Quelles que puissent être les oppositions que M. Venetz a rencontrées, je crois que le moyen qu'il a choisi est parfaitement rationnel, puisqu'il est justifié par l'expérience que je viens d'indiquer. Je n'ai pu savoir si ses tentatives ont obtenu le succès qu'il en attendait.

Reportons maintenant notre expérience sur les glaciers. L'eau de la pluie, l'eau qui se forme par la condensation des vapeurs, l'eau qui provient de la fusion des glaces, arrivent sur les deux bords du glacier; mais comme elles partent du milieu, leur quantité sera plus grande à mesure qu'elles s'approcheront

the bank, and their effect in producing fusion will be more considerable; the ice, therefore, must be lowered towards the edges, and the surface of the glacier will be a hog's back.

CHAPTER XI.

OF CREVASSES.

ALL who have described the Mer de Glace have employed the same term of comparison to give a just idea of it to those who have not seen it. "The surface "of the glacier," says M. de Saussure, "seen from the "Mont Envers, resembles that of a sea suddenly frozen, "not at a moment of actual tempest, but at an instant "when the wind is calmed, and the waves, though very "high, are with the crests off, and rounded." *

These irregularities of surface, so numerous, so varied in form, height, and arrangement, offer one of the most

* *Voyage dans les Alpes*, tome 2, page 6.

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de la rive, et leur effet pour la fusion sera plus considérable; les glaces devront donc s'abaisser vers les bords, et la surface du glacier sera un dos-d'âne.

CHAPITRE XI.

DES CREVASSES.

Tous ceux qui ont décrit la mer de glace ont employé le même terme de comparaison pour en donner une juste idée à ceux qui ne l'ont pas vue: "La surface du glacier, dit M. de "Saussure, vue du Mont-Envers, ressemble à celle d'une mer "qui aurait été subitement gelée, non pas dans le moment de "la tempête, mais à l'instant où le vent s'est calmé, où les "vagues, quoique très-hautes, sont émoussées et arrondies."*

Ces aspérités si nombreuses, si variées par la forme, l'élévation et l'arrangement, offrent un des spectacles les plus intéres-

* *Voyage dans les Alpes*, tome 2, pag. 6.

interesting spectacles that nature can furnish. Ridges of ice, often of considerable length, prolong themselves across the river of ice; their summits, although sharp enough, are not always uniform, but surmounted by aiguilles like the granite ridges of the high mountains. Between these ridges are little valleys transverse to the current. Their depth varies as the elevation of the ice-hills which bound them. It is these little valleys that are conventionally termed *crevasses*; but the same word is used to designate all the cavities met with in glaciers, whatever their origin or position. Confusion is thus introduced into our ideas respecting this department of nature. Let us seek to distinguish the things.

Masses of snow, and sometimes of ice, detach themselves from the mountain and flow rapidly along its flanks, leaving an open space, or, if you will, a trench, more or less wide and deep. To this cavity the name of *crevasse* is given; it would be better, as it seems to me, to call it a gully.

In places where the slope is rapid, the ice, yielding to its own weight, detaches itself from the mass above,

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sants que puisse fournir la nature. Des arêtes de glace souvent assez longues se prolongent au travers du fleuve de glace; leur sommet quelquefois assez tranchant, n'est pas toujours uniforme, mais surmonté d'aiguilles comme les arêtes granitiques des hautes montagnes. Entre ces arêtes se trouvent de petites vallées traversales au courant. Leur profondeur varie comme l'élévation des collines glacées qui les bornent. Ce sont ces petites vallées que l'on est convenu d'appeler crevasses; mais on se sert de ce même mot pour désigner toutes les cavités qui se rencontrent dans les glaciers, quelle que soit leur cause et leur position. C'est jeter de la confusion dans les idées qui ont rapport à cette partie de la nature. Cherchons à distinguer les choses.

Des masses de neige et quelquefois de glace, se détachent de la montagne et coulent rapidement le long de ses flancs, en laissant un vide, ou si l'on veut un fossé plus ou moins large et profond. On donne à cette cavité le nom de crevasse; il vaudrait mieux, ce me semble, l'appeler *couloir*.

Dans les endroits où la pente est rapide, la glace, cédant à sa propre pesanteur, se détache de la masse supérieure et s'avance

and advances towards to the bottom by a distance more or less great according to the room it finds. The void it leaves behind it is a true split, which is effected with great noise. This split will not be long in being closed by the approach of the ice above, which will descend in its turn, after the creation of another split higher up. To this opening again the name of *crevasse* is given: it would be better to leave it the name of *split*. I have observed several of these splits which had come into existence a short time before, perhaps some hours; they were open scarcely two inches in width, but they appeared to reach in depth to the bottom of the glacier, and to cut it perpendicularly to its sides; they were carried right across many crevasses, which they cut obliquely. The water which flows from the crevasses into the splits does not re-appear; a proof that the splits go to the bottom of the glaciers, whilst the crevasses are on the surface only. Lastly, there are, over the whole surface of *stream glaciers*, hollows which, as a general rule, affect only a certain thickness of the upper layer of the glacier without extending to the bottom; it is to these

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vers le bas d'une quantité plus ou moins grande, selon l'espace qu'elle trouve. Le vide qu'elle laisse derrière elle est une véritable fente qui s'est faite avec un grand bruit. Cette fente ne tardera pas à être fermée par l'approche de la glace supérieure, qui descendra à son tour après qu'une autre fente se sera faite plus haut. On donne encore le nom de crevasse à cette ouverture; il vaudrait mieux lui laisser le nom de fente. J'ai observé plusieurs de ces fentes qui avaient été faites depuis peu de temps, depuis quelques heures peut-être; elles n'avaient guère que deux pouces d'ouverture, mais en profondeur elles paraissaient s'étendre jusqu'au fond du glacier, et en le coupant perpendiculairement à ses bords; elles se propageaient à travers beaucoup de crevasses qu'elles coupaient obliquement. L'eau qui coule des crevasses dans les fentes ne reparaît pas; ce qui prouve que les fentes vont au fond des glaciers, tandis que les crevasses ne sont qu'à la superficie. Enfin, il y a sur toute la surface des *glaciers d'écoulement*, des enfoncements qui, pour l'ordinaire, n'affectent qu'une certaine épaisseur de la couche supérieure du glacier sans s'étendre jusqu'au fond; c'est

little valleys that I keep the name of crevasse, which has always been given to them. They are what would be called in geology valleys of erosion: the action of sun, vapour, and the flow of water have lent mutual assistance to their production.

Let us enter into details. The ice is not everywhere equally fusible; the more porous portions—those which contain little nests of earthy substance—melt more rapidly. The water produced by melting, in taking its course towards the bank, if it meets with a slope, soon hollows out for itself a little channel, and if there is no slope, reposes on itself and forms a well, a sort of little lake which becomes often very deep, and may pierce the glacier from place to place, and so empty itself below. But, before speaking of wells, let us return to the little open channel which gives passage to the waters produced by melting. It soon receives the waters of its own two banks, and, as we have seen that water possesses a great power of melting ice, the channel is hollowed out more and more, and becomes a regular trench, then a small valley; and if there be another in its neighbourhood parallel to it, the ice which sepa-

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à ces petites vallées que je conserve le nom de crevasse qu'on leur a toujours donné. C'est ce que l'on appellerait en géologie les vallées d'érosion; l'action du soleil, la vapeur et l'écoulement des eaux se sont prêté un mutuel secours pour les produire.

Entrons dans les détails: la glace n'est pas partout également fusible; les parties les plus poreuses, celles qui contiennent de petits nids de substance terreuse se fondent plus rapidement. L'eau de fusion en se dirigeant vers la rive, si elle rencontre une pente, se creuse bientôt un petit canal, et s'il n'y a point de pente, reste sur elle-même et forme un puits, une espèce de petit lac qui devient souvent très-profond, et peut percer le glacier de part en part pour se vider au-dessous. Mais avant de parler des puits, revenons au petit canal ouvert qui donne l'écoulement aux eaux de fusion, Il reçoit bientôt les eaux de ses deux rives, et, comme nous avons vu que l'eau a un grand pouvoir pour fondre la glace, le canal se creuse de plus en plus et devient un véritable fossé, puis une petite vallée, et s'il y en a un dans son voisinage qui lui soit parallèle, la glace qui les sépare devient une arête, une véritable colline sur laquelle les

rates them becomes a ridge—a regular hill on which the harder and less fusible portions form aiguilles, pyramids, &c. The walls of *crevasses* washed and polished by water, the result of melting, become glittering, and of an extremely agreeable aqua-marine green. This is not all: the *crevasses* on the Glacier des Bois assume a form which no naturalist has observed. If we enter upon the glacier, and halt a quarter of the way across, we see, if we turn round towards its source, as it were a battalion of points, scarped ramparts, aiguilles, often more than twenty feet high, presented to the view; and if we turn towards the lower part of the glacier, the surface seems almost unbroken. I sought for the reason of so extraordinary a difference, and found it at once in the form of the ridges of ice which separate the *crevasses*. They have all a precipitous side and a side of gentle inclination, so that if one saw a certain number of them in profile they would have pretty much the appearance of the subjoined figure. Looking up the glacier we see the scarped side of all the ridges, which display themselves one above another; and turning towards the lower part, we see the gentle slopes, which melt together into

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parties les plus dures et les moins fusibles forment des aiguilles, des pyramides, etc. Les parois des crevasses lavées et polies par l'eau de fusion sont devenues luisantes et d'un vert d'aigue-marine extrêmement agréable. Ce n'est pas tout: les crevasses ont sur le glacier des Bois une forme qu'aucun naturaliste n'a observée. Si l'on entre sur le glacier, et que l'on s'arrête après un quart de la traversée, en se retournant vers sa source, on voit comme un bataillon de pointes, de remparts escarpés, d'aiguilles, souvent élevées de plus de vingt pieds, s'offrir aux regards; et si l'on se tourne vers le bas du glacier, la surface semble presque unie. J'ai cherché la raison d'une différence aussi extraordinaire, et je l'ai à l'instant trouvée dans la forme des arêtes de glace qui séparent les crevasses. Elles ont toutes un côté escarpé et un côté à pente douce, de sorte que si l'on en voyait un certain nombre en profil, elles auraient à peu près l'aspect de la figure ci-contre. En regardant vers le haut, on voit la partie escarpée de toutes les arêtes qui se dessinent les unes sur les autres, et en se retournant vers le bas, on voit les pentes douces qui se confondent en une seule pente presque

one nearly uniform slope. The contrast is so great that I am astonished observers have not been struck by it.

This arrangement of the ridges of ice is a consequence of the direction of the glacier with respect to the sun; it goes nearly from south to north. This direction being given, let us see what must be the effect produced upon a slice of ice.

Let A B C be the ridge seen in profile; the rays of the sun following the line S A will strike the whole of the part A C of the ridge; and the water, increasing the melting as it flows to the bottom of the crevasses, will add to itself the products of fusion, so that the melting will go on increasing from the point A to the point C, whilst the part A B, which is pro-

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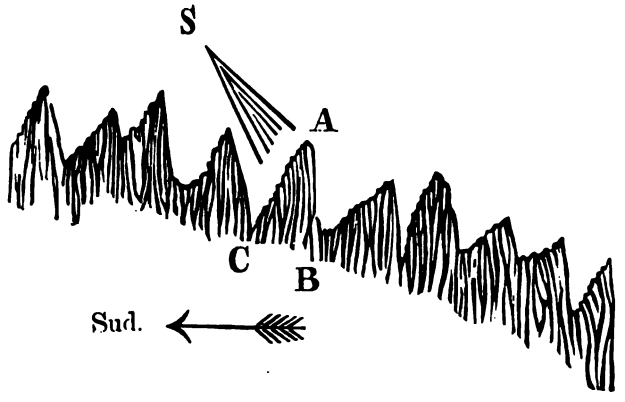
uniforme. Ce contraste est si grand que je suis étonné qu'il n'ait pas frappé les observateurs.

Cette disposition des arêtes de glace est une conséquence de la direction du glacier par rapport au soleil: il va à peu près du sud au nord. Cette direction étant donnée, voyons quel doit être l'effet produit sur une tranche de glace.



Soit l'arête A B C, vue de profil; les rayons solaires suivant la ligne S A frapperont toute la partie A C de l'arête, et les eaux en coulant au fond de la crevasse augmentant la fusion, l'ajouteront à elle-même, de manière que la fusion ira croissant du point A jusqu'au point C, tandis que la partie A B, préservée

tected from the sun, will not melt at all. I may be accused of taking the effects already produced as the basis of my demonstration; but it is easy to see that this reasoning is as applicable to the first moment of melting as to the last; if we choose to take the crevasse while it is but $\frac{1}{12}$th of an inch deep, the effect pointed out will then be the most appreciable.

The roughnesses of surface of the Glacier des Bossons do not resemble those of the Mer de Glace. Instead of ridges bevelled towards the summit, they are regular pyramids, obelisks of ice. This difference of form is a fresh piece of evidence in favour of my demonstration, for it is due to the difference of position. The Glacier des Bossons, resting upon the northern side of the mountain, scarcely receives the rays of the sun at all; the melting being nearly uniform, the water flows from every side in equal quantities, and forms pyramids instead of the ridges which, as we have seen, it produces on the Glacier des Bois.

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du soleil, ne fondra point du tout. On pourrait m'accuser de prendre des effets déjà produits pour base de ma démonstration; mais il est facile de voir que ce raisonnement peut s'appliquer au premier moment de la fusion comme au dernier; si l'on veut prendre la crevasse pendant qu'elle n'a qu'une ligne de profondeur, c'est alors que l'effet indiqué sera le plus sensible.

Les aspérités du glacier des Bossons ne ressemblent pas à celles de la mer de glace. Au lieu d'arêtes taillées en biseau vers les sommets, ce sont de véritables pyramides, des obélisques de glace. Cette différence de forme est une nouvelle preuve en faveur de ma démonstration, car elle est due à la différence de position. Le glacier des Bossons appuyé au nord de la montagne, ne reçoit presque pas les rayons du soleil; la fusion étant à peu près uniforme, les eaux coulent de tous côtés en égale quantité, et forment des pyramides au lieu de former des arêtes, comme nous l'avons vu au glacier des Bois.

CHAPTER XII.

OF WELLS IN STREAM GLACIERS.

We meet sometimes with cavities of great vertical depth, and these cavities, filled with water to the surface, take the name of wells. This name would seem to imply that they are always rounded; but such is not the fact. These cavities affect all sorts of forms: sometimes we have a little hole which becomes all at once wider and then contracts again; oftentimes we have an elongated crevasse; sometimes a little pool with sinuous edges; and then again a regular well. We can understand that its prolongation in the mass of the ice must narrow and open out according as the layers of ice it meets with are more porous or more compact. The depth of these cavities is often very great, and may sometimes reach the bottom of the glacier, and then the water descends and follows the bottom of the valley beneath the vaults of ice which receive all the water produced by melting.

CHAPITRE XII.

DES PUITS DANS LES GLACIERS D'ÉCOULEMENT.

On rencontre quelquefois des cavités d'une grande profondeur verticale, et ces cavites remplies d'eau jusqu'à la surface, prennent le nom de puits. Ce nom semblerait faire croire qu'elles sont toujours arrondies; mais il n'en est point ainsi. Ces cavités affectent toutes sortes de formes: quelquefois c'est un petit trou qui devient tout-à-coup plus large, et ensuite se rétrécit; souvent c'est une crevasse allongée, quelquefois un petit étang aux bords sinueux, et enfin un véritable puits. On comprend que son prolongement dans la masse glacée doit avoir des étranglements et des renflements selon que les couches de glace qu'il rencontre sont plus poreuses ou plus compactes. La profondeur de ces cavités est souvent très-grande et peut quelquefois atteindre le fond du glacier, alors l'eau descend et suit le fond de la vallée sous les voûtes de glace qui reçoivent toute l'eau de fusion.

How is it that the ice can have melted at a depth at which we can predicate the action neither of sun, nor of rain, nor internal heat, inasmuch as the bottom of the glacier is not always reached? A Swiss naturalist asserts that this mystery is inexplicable; the rest say nothing about it. With the knowledge we possess of the changes of density which water experiences in changing its temperature, and with the additional knowledge of the power it possesses of accelerating fusion, the phenomenon I have just pointed out is easy to conceive. Let us suppose, in fact, that melting takes place upon a portion of the glacier which has no inclination, and where, consequently, the water remains without running away: it collects upon the lowest point, and it is here that we shall witness its action in hollowing out the bottom of the reservoir in which it is gathered together.

The experiments of physicists have proved that water attains its maximum density at a temperature of 39° Fahrenheit, and that, starting from this point, its volume increases, whether upon a rise or upon a fall of the thermometer; but this increase is much more rapid

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Comment la glace a-t-elle pu se fondre à une profondeur où l'on ne peut alléguer ni l'action du soleil, ni celle des pluies, ni la chaleur interne, puisque le fond du glacier n'est pas toujours atteint? Un naturaliste Suisse prétend que ce mystère est inexplicable; les autres n'en parlent pas. Avec la connaissance que nous avons des changements de densité que l'eau éprouve en changeant de température, et cette autre connaissance du pouvoir qu'elle possède pour accélérer la fusion, le phénomène, que je viens d'indiquer est facile à concevoir. Supposons en effet qu'il y ait fusion sur une partie du glacier qui n'a aucune pente, et où, par conséquent, l'eau reste sans écoulement; elle se rassemble sur le point le plus bas, et c'est ici que nous allons voir son action pour creuser le fond du réservoir dans lequel elle se réunit.

Les expériences des physiciens ont prouvé que l'eau atteint son maximum de densité à la température de + 4° du thermomètre centigrade, et qu'en partant de ce point, son volume augmente, soit dans l'élévation, soit dans l'abaissement du thermomètre; mais cette augmentation est beaucoup plus rapide en

as we descend towards the freezing point than as we rise towards the boiling water point, inasmuch as in passing through 173° to arrive at the latter limit, its increase is only $\frac{1}{23}$ of its volume, whereas in going down 7° only to reach the freezing point, its increase is $\frac{1}{14}$. Now, let us apply our knowledge of this fact to the water of the wells of stream glaciers. The portion of the liquid lying at the surface being heated by the sun, the air, rain, or vapour, may very well be raised to three, four, five, or six degrees above the freezing point: it is then about at its maximum density. On the other hand, the portion of the liquid which is in contact with the ice at the bottom reaches a temperature very near the freezing point, and consequently it receives the greatest augmentation of volume of which it is susceptible; but in virtue of the law of hydrostatics, which ordains that liquids shall find their places at heights inverse to their weight, the water at the bottom must ascend, and that at the surface must descend. By this countermarch of the column of water, that which contained caloric has come to the bottom of the reservoir, and that which was cold has come to the surface, where it finds itself in contact with atmospheric influences.

descendant vers zéro qu'en montant vers l'eau bouillante, puisqu'en parcourant 96° pour arriver vers ce dernier terme, elle ne s'accroît que de $\frac{1}{23}$, tandis qu'en descendant de trois degrés seulement pour arriver à zéro, elle s'accroît de $\frac{1}{14}$. Appliquons maintenant la connaissance de ce fait à l'eau des puits des glaciers d'écoulement. La portion du liquide qui se trouve à la surface réchauffée par le soleil, l'air, la pluie ou la vapeur, peut bien s'élever à trois, quatre, cinq et six degrés au-dessus de zéro: alors elle est autour de son maximum de densité. Au contraire, la portion du liquide qui est en contact avec la glace du fond, arrive à une température très-proche de zéro, et par conséquent elle reçoit la plus grande augmentation de volume dont elle est susceptible; mais par cette loi de l'hydrostatique qui veut que les liquides se placent dans des élévations inverses à leur pesanteur, l'eau du fond devra monter et celle de la surface descendre. Par ce revirement de la colonne d'eau, celle qui contenait du calorique est parvenue au fond du réservoir, et celle qui était froide est venue à la surface, où elle se trouve en contact avec les agents atmosphériques. Que doit-il

What must happen in this new position? Why, that the excess of caloric which comes in contact with the ice is absorbed in a fresh act of melting, and the water at the bottom comes down again to the freezing point, whilst that at the surface acquires caloric, and rises again, perhaps, to between 38° and 43°. Hence a fresh change of position is again inevitable, and becomes so every moment; so that there exists in the cavity a motion of perpetual circulation from the bottom to the surface, and from the surface to the bottom: one might say, a mechanical agent put in force by an intelligent power to go and dig out the bottom of a reservoir.

When the melting season is long, or the well happens to be in a portion of the glacier of little depth or very porous, the bottom of the well reaches the bottom of the glacier, and in this case the water produced by melting which comes from the upper part of the glacier falls in the form of a cascade to the very soil on which the glacier rests, and so flows beneath the vaults of ice down to its extremity.

It not unfrequently happens that, when these wells are bottomless, and consequently without water, we hear, falling inside them, water which seems to come

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se passer dans cette nouvelle position? Le voici: le calorique en plus qui arrive en contact avec la glace est absorbé pour une fusion nouvelle, et l'eau du fond redescend à zéro, pendant que celle de la surface en acquiert et remonte à trois, quatre, cinq ou six degrés. Dès lors un nouveau changement de position est encore nécessaire et le redevient à chaque moment, de telle sorte qu'il y a dans cette cavité un mouvement de circulation perpétuelle du fond à la surface et de la surface au fond: on dirait un agent mécanique employé par une intelligence pour aller creuser le fond d'un réservoir.

Quand la saison de fusion est longue ou que le puits se trouve dans une partie du glacier peu profonde ou très-poreuse, le fond du puits atteint le fond du glacier, et dans ce cas les eaux de fusion qui viennent de la partie supérieure tombent en cascade jusqu'au sol sur lequel repose le glacier, et coulent ainsi sous des voûtes de glace jusqu'à l'extrémité.

Il n'est pas rare que quand ces puits sont sans fond et sans eau par conséquent, on entende tomber dedans des eaux qui

out of the walls of living ice which surround the well. This is easily explained. The mass of the glacier is, as we have seen, formed of different layers in superposition, and the connecting layers which separate them are often of ice studded with bubbles, or of less compact snow. Hence it arises, that when the water which flows to the bottom of a crevasse happens to meet with these portions of less resistance, it melts them, and, spreading laterally, meets with the well and precipitates itself into it as a roaring waterfall.

CHAPTER XIII.

OF MORAINES.

M. VENETZ gives, with respect to the formation of moraines, an explanation which appears to me little in accordance with observation. It is as follows:—"In "their increase, glaciers have the property of *pushing* "*before them* earth, stones, and all foreign bodies; for

semblent sortir des parois de glace vive qui entourent le puits. Ceci s'explique facilement. La masse du glacier est, comme nous l'avons vu, formée de diverses couches superposées, et les joints qui les séparent sont souvent de glace bulleuse, ou de neige moins compacte. Dès lors quand les eaux qui coulent au fond d'une crevasse viennent à rencontrer ces parties moins résistantes, elles les fondent, et en se propageant latéralement, elles rencontrent le puits et s'y précipitent en cascade bruyante.

CHAPITRE XIII.

DES MORAINES.

M. Venetz donne sur la formation des moraines une explication qui me paraît peu conforme à l'observation; la voici: "Dans "leur accroissement, les glaciers ont la propriété de *pousser* "*devant eux* les terres, les pierres et tous les corps étrangers;

"this reason, these materials almost always surround "the foot of these enormous masses of ice, forming a "slope of about forty-five degrees, &c. . . . " One would say, according to this notion, that moraines once pushed to a certain point by glaciers are incapable of further increase; there is a mistake: it is not by *pushing* that glaciers form moraines; it is by transportation, by carriage of the materials. All this will be better understood by the mere description of the phenomena.

At the bottom and on the edges of stream glaciers we find heaps of rocks, of angular stones, of sand, and of earth which have been deposited there by the glacier. It is in every case a river, which deposits on its banks a part of the substance which it transports, and which carries off the rest down to its embouchure. The name of moraine is given to the deposits made by glaciers. Some of these moraines present the aspect of immense embankments constructed at the edge of a stream to confine it to its bed.

I have said, in speaking of the form of stream-glaciers, that they were higher towards the middle. In proportion as they melt, the waters which are borne against

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"par cette raison, ces matériaux entourent presque toujours le "pied de ces énormes masses de glace en formant un talus "d'environ quarante-cinq degrés, etc...." On dirait, d'après ces idées, que les moraines une fois poussées sur un point par les glaciers, ne sont plus susceptibles d'accroissement; il y a erreur: ce n'est point en *poussant* que les glaciers forment les moraines; c'est en charriant, en portant les matériaux. Tout ceci se comprendra mieux par la seule exposition des phénomènes.

Au fond et sur les bords des glaciers d'écoulement on trouve des amas de rochers, de cailloux anguleux, de sable et de terre qui ont été déposés là par le glacier. C'est toujours un fleuve qui dépose sur ses rives une partie des substances qu'il charrie, et qui emporte les autres jusqu'à son embouchure. On donne le nom de moraines aux dépôts fait par les glaciers. Quelques-unes de ces moraines présentent l'aspect d'immenses chaussées fondées au bord d'un fleuve pour le fixer dans son lit.

J'ai dit en parlant de la forme des glaciers d'écoulement, qu'ils étaient plus élevés vers le milieu. A mesure qu'ils fondent, les eaux qui se portent sur les rives entraînent avec elles la terre et

the banks carry off with them the earth and sand met with in the ice; the rocks which happen to be on the two slopes must themselves find their way little by little towards the shores; so that every day brings an increment to these lofty ramparts which are in front of the glaciers. It is not, however, on the banks that the greatest quantity of matter is found; it is at the end of the glacier, at the point where its resistance is overcome by heat, and where the materials which it was bearing in its interior, as well as those which it transports on its surface, remain in the open. There we behold these heaps of matter piled up in hills, and indicating by their position the different points at which the glacier has stayed its march. In an address delivered before the "*Société Helvétique des Sciences Naturelles*," the president, M. Agassis, said that the blocks of rock which compose a moraine are rounded; it is a mistake; all the blocks of *active* moraines are angular, often even with sharp edges, with flat surfaces of more or less extent. The rounded blocks are those which have been rolled by water. The latter, always more or less polished, are easy to recognize. The blocks which form

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le sable qui se trouvent dans les glaces; les rochers qui se trouvent sur les versants doivent eux-mêmes couler peu à peu vers le rivage; de sorte que chaque jour apporte un accroissement à ces remparts élevés qui devancent les glaciers. Pourtant ce n'est pas sur les rives que se trouve la plus grande quantité de matière, c'est au bout du glacier, là où sa résistance est vaincue par la chaleur et où restent à découvert les matériaux qu'il portait dans son intérieur, aussi bien que ceux qu'il charrie à sa surface. Là on voit ces amas de matières entassées en collines, et indiquant par leur position les divers points vers lesquels le glacier s'est arrêté. Dans un discours prononcé dans la *Société Helvétique des Sciences naturelles*, le président, M. Agassis, a dit que les blocs de rochers qui forment les moraines sont arrondis; c'est une erreur; tous les blocs des moraines actuellement en action sont des blocs anguleux, souvent même à arêtes vives, avec des faces planes plus ou moins étendues. Les blocs arrondis sont ceux qui ont été roulés par les eaux. Ces derniers, toujours plus ou moins polis, sont faciles à reconnaître. Les blocs des moraines ont souvent les angles brisés,

moraines often have their corners broken, but rarely rounded, which is a very different thing. As to the flat surfaces—polished sometimes—of the masses transported by the glaciers, they indicate the point of separation from the parent mass. Talcose micaceous rocks, protogines, and sometimes also calcareous strata, present, on splitting off, tolerably polished surfaces.

M. Godefroi has adopted, in the work he has just published, the same theory as M. Venetz. According to this author, the small transverse valleys which seam the flanks of lofty mountains are filled with the *débris* of these same mountains. Taking its departure from the reservoir glaciers to descend into the zone where melting takes place, the ice has pushed before itself, and to some extent thrown off on its flanks, the stony and earthy *débris* which it has met with on its passage, pretty much as the ploughshare which raises the soil carries it in front of itself and heaps it up on the two sides of the furrow. Such is the theory of M. Godefroi, which, in my opinion, differs from that of M. Venetz only in details. This theory is altogether contrary to observation. I do not care to remark upon the improbability there is in the notion of ice insinuat-

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mais rarement arrondis, ce qui est bien différent. Quant aux surfaces planes et quelquefois polies de ces masses que portent les glaciers, elles indiquent le point de délitement. Les roches talqueuses micassées, les protogines, et quelquefois aussi les strates calcaires, en se délitant offrent des surfaces assez polies.

M. Godefroi a admis, dans l'ouvrage qu'il vient de publier, le même système que M. Venetz. D'après cet auteur, les petites vallées transversales qui descendent par le flanc des hautes montagnes, sont remplies des débris de ces mêmes montagnes. En partant des glaciers-réservoirs pour descendre dans la zone de fusion, les glaces ont poussé devant elles et en partie rejeté sur leurs flancs les débris pierreux et terreux qu'ils ont trouvés sur leur passage, à peu près comme le soc de la charrue qui soulève la terre, la porte en avant et la redresse des deux côtés du sillon. Telle est la théorie de M. Godefroi, qui, selon moi, ne diffère de celle de M. Venetz que par les détails. Ce système est entièrement contraire à l'observation. Je ne veux pas relever ce qu'il y a d'invraisemblable dans ces glaces qui s'insinuent à

ing itself after the fashion of a ploughshare into the *débris* of rocks, and lifting them up on its sides; I will content myself with calling to the attention of the reader that, almost contemporaneously with the formation of the mountains, the reservoir glacier was itself formed and supplied ice to the stream glaciers before the transverse valleys or ravines had been filled with the *débris* of the mountains. We have here a preliminary question which cuts the difficulty; it is not in that direction that we must seek the solution of this problem, which is, moreover, of great simplicity. All the elements needed by the understanding in order to arrive at it are at hand; we have only to observe them. I repeat, the surface of the glacier is laden with *débris* which has come with the ice from the mountain tops. The glacier is in general of a convex form; it is therefore perfectly obvious, that, as it descends, part of the blocks of rock advance slowly towards the sides, and at last fall there. A certain number of them can be seen, which are ready to take the last step in this manœuvre.

As to the sand, as to the earthy particles which enter into the composition of *moraines*, it is just as evident that

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la manière d'un soc dans les débris des roches pour les soulever sur les côtés; je me contenterai de faire observer au lecteur qu'aussitôt après la formation de la montagne, le glacier-réservoir s'est lui-même formé et a fourni des glaces aux glaciers d'écoulement avant que les vallées transversales ou que les couloirs eussent été remplis par les débris des montagnes. C'est ici une question préjudicielle qui tranche la difficulté; ce n'est pas là qu'il faut chercher la solution de ce problême, qui est d'ailleurs d'une grande simplicité. Tous les éléments dont l'intelligence avait besoin pour y arriver sont là; il ne faut que les observer. Je le répète, la surface du glacier est chargée de débris venus avec les glaces des sommités de la montagne. Le glacier est en général d'une forme convexe; il est donc tout simple qu'à mesure qu'il descend, partie des blocs de rochers s'avancent lentement vers les bords et finissent par y tomber. On en voit un certain nombre qui sont près de terminer cette évolution.

Quant aux sables, aux parties terreuses qui entrent dans l'ensemble des moraines, il est tout aussi évident qu'elles n'ont

they have no other origin; if we stoop over one of the little rivulets which flow at the bottom of crevasses, we see passing in this water, limpid as it is, which flows over a floor of emerald, little black grains, which are the sand come with the ice, and which are on their way to form an addition to the *moraines*. It is true that it is but a grain of sand added to a small mountain; but the grain which is always coming, ends by building up a mass.

I will add a last observation, which is just as conclusive against the theory of M. Godefroi. A great number of glaciers have several lines of lateral *moraines*; I will instance the Glacier of Rosboden, near the Simplon; and to call attention to a glacier better known, I will recur to the Glacier des Bois. On the edge of the Mer de Glace, below the pavilion of the Mont Envers, I recognized three stages of *moraines*, including that which is actually in course of formation. The most ancient is more than sixty feet higher than this last. Will it be said that the glacier has begun its furrow afresh three times? It would be absurd. We know that this glacier has greatly diminished, and that in the same way as it has left ancient *moraines* at the bottom of the

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pas une autre origine; en se baissant sur l'un de ces petits ruisseaux qui coulent au fond des crevasses, on voit passer dans cette eau si limpide qui coule sur un fond d'émeraude, de petit grains noirs qui sont les sables venus avec les glaces, et qui vont s'ajouter aux moraines; il est vrai que ce n'est qu'un grain de sable ajouté à une petite montagne; mais le grain qui vient toujours finit par faire une masse.

J'ajouterai une dernière observation qui est tout aussi concluante contre le système de M. Godefroi. Un grand nombre de glaciers ont plusieurs lignes de moraines latérales; je citerai pour exemple le glacier de Rosboden près du Simplon; et pour m'arrêter à un glacier plus connu, je reviendrai au glacier des Bois. Sur le bord de la mer de glace, au-dessous du pavillon du Mont-Envers, j'ai reconnu trois étages de moraines, en y comprenant celle qui est actuellement en état de formation. La plus ancienne est plus de soixante pieds plus élevée que cette dernière. Dira-t-on que le glacier a recommencé trois fois son sillon? Ce serait absurde. Nous savons que ce glacier a beaucoup diminué, et de même qu'il a laissé d'anciennes moraines

valley, it has also left on its banks *moraines* corresponding to its former height.

CHAPTER XIV.

OF ERRATIC BLOCKS.

The rocks of all sizes and all shapes which are collected at the extremity of a glacier have not, generally speaking, any analogy with those supplied by this portion of the valley. To discover their congeners, we must ascend towards the sources of the glacier. Hence travellers have conferred upon these rocks the name of *erratic*. Rocks of a like character, and bearing the same name, are found scattered through all the valleys of the Alps, on mountain sides, and in the plains. Naturalists have bestowed much attention upon the search after causes capable of having transported these masses so far from the place of their origin, and when the reflec-

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au fond de la vallée, il en a aussi laissé sur ses côtés qui correspondent à son ancienne élévation.

CHAPITRE XIV.

DES BLOCS ERRATIQUES.

Les rochers de toutes les grandeurs et de toutes les formes qui sont rassemblés à l'extrémité des glaciers, n'ont pour l'ordinaire aucune analogie avec ceux que fournit cette portion de la vallée. Pour retrouver leurs analogues, il faut remonter vers les sources du glacier. On a donc donné à ces rochers voyageurs le nom d'erratiques. On en trouve de semblables et portant le même nom, répandus dans toutes les vallées des Alpes, sur le flanc des montagnes et dans les plaines. Les naturalistes se sont beaucoup occupés de chercher les causes qui avaient pu transporter ces masses aussi loin du lieu de leur origine, et

tion occurred to them that glaciers actually in action carried rocks from the top of the Alps down to the bottom of the valleys, they multiplied this cause, and increased its magnitude till it became sufficient to account for all the effects produced; but it needed gigantic glaciers to transport rocks the length of the valley of the Rhone, from the St. Gothard to the extremity of the Jura, and from the summit of the latter mountain to the summits of inferior hills. They have not allowed themselves to be brought to a standstill by this difficulty, and have assigned to the glaciers the stature necessary to produce the effects of which they desired to give the origin. It is to M. Venetz, the engineer of the Canton of Valais, that we owe the ingenious theory of which I am going to give the analysis.

After I know not how many deluges and revolutions, which were absolutely necessary to render intelligible to our minds the geological facts observed in these countries, we behold suddenly rising to the surface of the globe two vast granitic masses—the one in the Valais, and the other in Savoy. That in Savoy comprehends the whole of the enormous group of rocks,

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quand la réflexion leur est venue que les glaciers actuellement en action portaient des rochers du haut des Alpes jusque dans le bas des vallées, ils ont multiplié cette cause et l'ont agrandie jusqu'à ce qu'elle pût s'étendre à tous les effets produits; mais il fallait des glaciers gigantesques pour conduire des rochers le long de la vallée du Rhône, depuis le Saint-Gothard jusqu'à l'extrémité du Jura, et depuis le sommet de cette dernière montagne jusqu'au sommet des collines inférieures. On ne s'est pas laissé arrêter par cette difficulté, on a donné aux glaciers la taille nécessaire pour produire les effets dont on voulait donner l'origine. C'est à M. Venetz, ingénieur du canton du Valais, que l'on doit le système ingénieux dont je vais donner l'analyse.

Après je ne sais combien de cataclysmes et de révolutions qui étaient tout à fait nécessaires pour rendre intelligibles à notre esprit les faits géologiques observés dans ces contrées, on voit surgir tout à coup à la surface du globe deux vastes masses granitiques, l'une dans le Valais, et l'autre dans la Savoie. Celle de la Savoie comprend tout le massif énorme de roches dont la

the loftiest summit of which is Mont Blanc. This granite, porphyry, serpentine, and all these crystalline rocks—which very certainly have a Plutonian origin, and which, consequently, were formed in the heart of the central fire—have come to the light of day through the gneisses, the mica-schists, and the other talcose and schistose rocks which were immediately below the Jurassic deposit. This immense effort of subterraneous nature acting upon the whole of this part of the globe, caused in it a vast upheaval, which raised the mountains already in existence, the valleys and the Alps, well above their present height. According to calculations, the summit of Mont Blanc must have been raised 18,834 feet above the level of the sea—that is to say, higher than all known mountains, and the lower valleys in the same proportion.

Then, the temperature must have sunk, the atmosphere must have cooled, the central heat must have diminished; the new Alps must have been covered with snow, and given rise to immense glaciers, which invaded all the valleys, and covered Switzerland with *moraines* and erratic blocks. This excessive elevation

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sommité la plus élevée est le Mont-Blanc. Ce granite, ce porphyre, cette serpentine et toutes ces roches cristallines, qui ont bien certainement une origine plutonienne, et qui, par conséquent, se sont formées dans le sein du foyer central, se sont fait jour à travers les gneiss, les micachistes et les autres roches talqueuses et schisteuses qui étaient immédiament au-dessous du dépôt jurassique. Cet immense effort de la nature interne agissant sur toute cette partie du globe, lui fit une vaste boursoufflure qui éleva les montagnes déjà existantes, les vallées et les Alpes, bien au-dessus de la hauteur qu'elles ont maintenant. D'après les calculs, le sommet du Mont-Blanc devait être élevé de 18,834 pieds au-dessus du niveau de la mer, c'est-à-dire plus élevé que toutes les montagnes connues, et les vallées inférieures dans cette même proportion.

Alors la température a dû s'abaisser, l'atmosphère se refroidir, la chaleur centrale diminuer; les Alpes nouvelles ont dû se couvrir de neige et donner lieu à d'immenses glaciers, qui envahirent toutes les vallées et couvrirent la Suisse de moraines et de blocs erratiques. Cependant cette élévation exorbitante

however could not last; the masses sank down little by little, and in thus returning on themselves, left to the ground the conformation it now possesses; which is intermediate between the first condition, in which the soil produced palm trees, fan palms, and other plants of the torrid zone, and the second condition, in which nearly the whole of it was covered with ice. Thus it is that the erratic blocks are found so far from the high Alps, whence they took their departure. I am too little disposed to give my adherence to theories so painfully elaborate, to have faith in that of M. Venetz. Everything which requires a great complication of means and causes is less adapted to unfold nature, always simple in her action, because rich and powerful in her resources, than to betray the feebleness of the human mind, which is limited in its conceptions. Whilst treating the whole thing as the product of a fertile imagination, I wish nevertheless to point out the error into which one of the partizans of the theory of M. Venetz has fallen. M. De Charpentier, in a memoir published in the *Bibliothèque Universelle de Genève* (July, 1836), has developed the consequences of the theory of glaciers

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ne pouvait durer; les masses s'affaissèrent peu à peu, et dans ce retour sur elles-mêmes, laissèrent au terrain la conformation qu'il possède maintenant, laquelle se trouve intermédiaire entre le premier état où le sol produisait les palmiers, les chamærops et d'autres plantes de la zone torride, et le second état où les glaces le couvraient presque tout entier. Voilà comment les blocs erratiques sont si loin des hautes Alpes, d'où ils sont partis. Je suis trop peu disposé à admettre les systèmes aussi péniblement élaborés, pour avoir foi à celui de M. Venetz. Tout ce qui exige une grande complication dans les moyens et dans les causes, est moins propre à découvrir la nature, toujours simple dans son action, parce qu'elle est riche et puissante dans ses ressources, qu'à déceler la faiblesse de l'esprit humain, qui est borné dans ses conceptions. En admettant le tout comme le produit d'une imagination facile, je veux cependant relever l'erreur dans laquelle est tombé l'un des partisans du système de M. Venetz. M. de Charpentier a, dans un Mémoire publié dans la *Bibliothèque universelle de Genève* (juillet 1836), développé les conséquences du système des glaciers considérés

considered as carriers of erratic blocks To determine the height of Mont Blanc at this epoch, and even the height of the valleys of Switzerland in which erratic blocks are found, and in which consequently glaciers must necessarily have existed, M. de Charpentier reasons thus:—

Glaciers are permanent only in regions where the mean temperature does not exceed 45·5°, as it does at Chamonix. The mean temperature of the valley of the Rhone therefore was, at the glacier epoch, 45·5°; but to bring down this mean temperature to 45·5°, it would be necessary to raise the whole district by as many toises as would be necessary to reduce it to that point; and as it is no longer at this elevation, it must have come down again from it. The whole of this calculation, which seems right, falls with the first supposition, which is false, or which at least is not in harmony with the nature of stream glaciers. M. de Charpentier starts from the supposition that glaciers can only be maintained at the mean temperature of 45·5°. This is not in accordance with observation. Temperature is but the least of the elements that must be taken into considera-

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comme vecteurs des blocs erratiques. Pour déterminer la hauteur du Mont-Blanc à cette époque, et de même la hauteur des vallées de la Suisse où se trouvent les blocs erratiques, et par conséquent où se sont nécessairement trouvés les glaciers, M. de Charpentier a raisonné ainsi:—

Les glaciers ne sont en permanence que dans un pays où la température moyenne ne dépasse pas + 6°, comme on le voit à Chamonix. Donc la température moyenne de la vallée du Rhône était, à l'époque des glaciers, de + 6°; mais pour ramener cette température moyenne à + 6°, il faudrait élever le pays tout entier d'autant de toises que la chose serait nécessaire pour l'y réduire, et puisqu'il ne se trouve plus à cette hauteur, il en est donc redescendu. Tout ce calcul, qui paraît juste, tombe avec la première supposition, qui est fausse, ou qui du moins n'est pas en harmonie avec la nature des glaciers d'écoulement. M. de Charpentier part de la supposition que les glaciers ne peuvent se maintenir qu'à la température moyenne de + 6°. Ceci n'est pas conforme à l'observation. La température n'est que le moindre des éléments qu'il faut considérer dans l'abaisse-

tion with respect to the descent of glaciers. Their prolongation into the valleys is due mainly to the quantity of ice supplied by the reservoir glacier; such a glacier, which receives but little ice, comes down no farther than about to a mean temperature of 38·75°, like the Glacier des Pélérins; such another which has received more of it comes down about to a temperature of 43·25°; and if the Glacier des Bois had a double quantity of ice to melt, we should perhaps see it come down along the valley of Chamonix to near Les Ouches, or still lower; and if it was the only point of outflow open to the whole of the ice-system formed on the different plateaux of Mont Blanc, I should not be surprised if it came down to the region of vine vegetation. This first basis being destroyed, all the superstructure falls of itself.

Nor is this all; the means invented to account for the origin of erratic blocks are still insufficient; for this phenomenon, which is of immense extent, must have everywhere the same cause; but I doubt much whether the cause invented by the naturalists of the Canton de Vaud could be applied to all the countries in which its action would be necessary. Erratic blocks are not con-

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ment des glaciers. Leur prolongement dans les vallées est dû surtout à la quantité des glaces fournies par le glacier-réservoir; tel glacier qui n'en reçoit que peu, ne descend que vers une température moyenne de + 3°, comme le glacier des Pélérins; tel autre qui en a reçu davantage, descend vers une température de + 5°; et si le glacier des Bois avait une double quantité de glace à fondre, nous le verrions peut-être descendre le long de la vallée de Chamonix jusque vers les Ouches, ou plus bas encore; et s'il était le seul point d'écoulement ouvert à toutes les glaces qui se forment sur divers plateaux du Mont-Blanc, je ne serais point étonné qu'il descendît jusqu'à la région végétale de la vigne. Cette première base étant détruite, tout l'échafaudage tombe de lui-même.

Ce n'est pas tout; le moyen inventé pour expliquer l'origine des blocs erratiques est encore insuffisant, car ce phénomène, qui a une immense étendue, doit avoir partout la même cause; mais je doute beaucoup que la cause inventée par les naturalistes vaudois puisse s'appliquer à tous les pays où son action serait

fined to the valleys of the Alps; they are found everywhere that we meet with the diluvian deposit, which displays itself in every part of the globe. They are sometimes seen isolated, but more often in groups and accumulated at certain points. We find great trails of them in the plains of the North, from the coasts of Northumberland to the environs of Moscow. The sandy plains of Westphalia, of Hanover, of Holstein, of Zealand, of Mecklenburgh, of Brandenburg; the plains of Pomerania and Prussia are covered with them. Iceland, which is entirely composed of volcanic substance, presents upon its loftiest summits blocks of granite more than ten metres thick. How can all these facts be explained by glaciers?

If, however, we are absolutely determined to attribute to the glaciers the transportation of the erratic blocks of the Alpine system, we might, as it seems to me, by following the series of successive dilapidations which the mountains have undergone down to the present day, arrive at an epoch at which the plateau of the Alps—without being more elevated than it is at the present day—was sufficiently extended to supply the

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nécessaire. Les blocs erratiques ne sont pas bornés aux vallées des Alpes; ils se retrouvent partout où l'on rencontre le dépôt diluvien qui se manifeste sur toutes les parties du globe. On les voit quelquefois isolés, et plus souvent groupés et accumulés sur certains points. On en trouve de grandes traînées dans les plaines du Nord, depuis les côtes du Northumberland jusqu'aux environs de Moscou. Les plaines sablonneuses de la Westphalie, du Hanôvre, du Holstein, de la Seelande, du Mecklembourg, du Brandebourg; les plaines de la Poméranie et de la Prusse en sont couvertes. L'Islande, qui est toute de substance volcanique, offre sur ces cimes les plus élevées des blocs de granite de plus de dix mètres d'épaisseur. Comment expliquer tous ces faits par des glaciers?.....

Si pourtant on veut absolument attribuer aux glaciers le transport des blocs erratiques du système alpin, on pourrait, ce me semble, en suivant la chaîne des dégradations successives que les montagnes ont subies jusqu'à nos jours, arriver à l'époque où le plateau des Alpes, sans être plus élevé qu'il ne l'est aujourd'hui, était assez étendu pour fournir des

ice and snow capable of filling all the valleys which surrounded it.

In point of fact, daily observation shows us that the summits get lower, that the flanks of the mountains contract, that their mass, in a word, diminishes, and is consumed by the action of atmospheric agents; and, at the same time that the peaks get lower, the foot of the mountain is covered with *débris*, so that their height is diminished at both extremes at once. Their materials descend from the summits, now in avalanches of earth, now in solid blocks which roll into the valley, now in small fragments and sandy particles, which render turbid the waters of the torrents, and go and deposit themselves in the plains, and on the very sea shore.

The present shape of the mountains is enough to demonstrate that they have lost much of their ancient magnitude. We find on their flanks transverse valleys which have evidently been hollowed out by the waters, or formed by the spontaneous fall of rocks which had been detached by weather from the parent mass. At the feet of precipitous walls stony *débris* has

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glaces et des neiges capables de remplir toutes les vallées qui l'entourent.

En effet, l'observation journalière nous prouve que les sommités s'abaissent, que les flancs des montagnes se rétrécissent, que leur masse, en un mot, diminue et s'use par l'action des agents atmosphériques; et en même temps que leurs cimes s'abaissent, leur pied se recouvre de débris; de sorte que la hauteur diminue par les deux extrémités à la fois. La matière descend des sommités tantôt en avalanches terreuses, tantôt en blocs solides qui roulent dans la vallée, tantôt en petits fragments et en parcelles sablonneuses qui troublent les eaux des torrents et vont se déposer dans les plaines et jusque sur le rivage des mers.

La forme actuelle des montagnes suffit pour démontrer qu'elles ont beaucoup perdu de leur antique grandeur. On trouve sur leurs flancs des vallées transversales, qui ont été évidemment creusées par les eaux ou formées par la chute spontanée de rochers que le temps avait détachés de la masse. Au pied des

arranged itself in banks, and it grows at the expense of the upper portions.

The isolated peaks, the aiguilles which rise above the masses of the great mountains are, as it were, witnesses, which have remained erect to tell us of the ancient elevation of the mountains; thus, the Aiguille du Dru, and the Aiguille de Charmoz, which display themselves above the Mont Envers, were certainly not planted there in the state in which they now are; but more solid and harder than the mass to which they have belonged, they have resisted the action of the atmospheric agents which have destroyed, or, at any rate, dispersed, the materials which filled the space separating the summits of these aiguilles from the summit of Mont Blanc. I might say as much of all the granitic summits of the Alps; but I wish merely to point out this notion.

To reconstruct the Alps as they must have been at one time, we should have to join to them all the tertiary hills which cover the plains, and rise in the longitudinal valleys on both sides of the Alps, all the alluvial earth which has served to bring to a level Lombardy, Pied-

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escarpements sont venus se ranger en talus des débris pierreux qui s'accroissent aux dépens des parties supérieures.

Les cimes isolées, les aiguilles qui dominent la masse des grandes montagnes, sont comme des témoins restés debout pour nous faire connaître l'ancienne élévation des montagnes; ainsi l'aiguille du Dru et l'aiguille de Charmoz, qui paraissent au-dessus du Mont-Envers, n'ont certainement pas été placées là dans l'état où elles sont actuellement; mais plus solides et plus dures que la masse à laquelle elles ont appartenu, elles ont résisté à l'action des agents atmosphériques qui ont détruit ou du moins dispersé les matériaux qui remplissaient l'espace qui sépare le sommet de ces aiguilles du sommet du Mont-Blanc. J'en pourrais dire autant de toutes les cimes granitiques des Alpes; mais je ne veux qu'indiquer cette idée.

Pour reconstruire les Alpes telles qu'elles ont dû être un jour, il faudrait y joindre toutes les collines tertiaires qui couvrent les plaines et s'élèvent dans les vallées longitudinales des deux côtés des Alpes, tout le terrain d'alluvion qui a servi à niveler la Lombardie, le Piémont, le plateau de la Bresse et les rives du

mont, the Plateau of Brescia, and the banks of the Rhone; all that has come down and carried farther seawards the coast line, whether at the mouth of the Rhone or at that of the Po; all the erratic blocks, in fine, which are to be found, sometimes isolated, sometimes in continuous lines across the valleys, and on the flanks of the mountains.

In that case, perhaps, we should have for the plateau of the Alps enough of elevation, and enough of surface, to supply glaciers capable of filling all the valleys which border upon them, and consequently to carry thither the *débris* of the loftiest granite summits.

CHAPTER XV.

OF THE ADVANCE AND RETREAT OF STREAM GLACIERS.

It is a pretty generally received prejudice that the lower part of a glacier is subject to periodical increase and decrease; that is to say, that the end of the

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Rhône; tout ce qui est venu écarter les rivages de la mer, soit à l'embouchure du Rhône, soit à celle du Pô; enfin tous ces blocs erratiques qui se trouvent tantôt isolés, tantôt en lignes continues à travers les vallées et sur le flanc des montagnes.

Alors peut-être on trouverait assez d'élévation et surtout assez de surface sur le plateau des Alpes pour fournir des glaciers capables de remplir toutes les vallées qui les avoisinent, et par suite d'y transporter les débris des sommités granitiques les plus élevées.

CHAPITRE XV.

AVANCEMENT ET RETRAITE DES GLACIERS D'ÉCOULEMENT.

C'est un préjugé assez généralement reçu, qu'il y a dans la partie basse du glacier des accroissements et décroissements périodiques; c'est-à-dire que le bout du glacier aurait un certain

glacier has a sort of *come-and-go* movement, a kind of oscillation whereby it alternately approaches to and recedes from the lower part of the valley. The inhabitants of mountain districts, little accustomed to be precise in their observations, have adopted the term of seven years to define the length of the period; and however little we may know how many different applications the number *seven* has in the language of mysteries, it is intelligible that this number must have been chosen to express a fact which has a real existence, but which is only vaguely known. In fact all travellers, who have desired to verify this phenomenon for themselves, have satisfied themselves that the fact of increase and decrease exists; but that it is subject to no law of regular recurrence. When we examine, as a whole, from an elevated spot, the localities in the neighbourhood of the end of the glacier, it is very easy to determine, by the aspect of the deposit, the extent over which the movement in question is being carried on. In the case of the Glacier des Bois, the difference between the greatest and least advance is only about 150 toises. Let us now inquire the cause of this move-

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mouvement de *va et vient*, espèce d'oscillation par laquelle il se rapprocherait et s'éloignerait alternativement du fond de la vallée. Les habitants des montagnes, peu habitués à mettre de la précision dans leurs observations, ont pris le terme de sept ans pour exprimer la longueur de la période; et pour peu que l'on sache combien le nombre *sept* a d'applications différentes dans le langage des choses mystérieuses, on comprend que ce nombre devait être choisi de préférence pour exprimer un fait qui a de la réalité, mais qui n'est connu que vaguement. En effet, tous les voyageurs qui ont voulu par eux-mêmes vérifier ce phénomène, se sont assurés que le fait des accroissements et des décroissements existe; mais qu'il n'est soumis à aucune loi de régularité. Quand on examine d'un endroit élevé l'ensemble des lieux qui avoisinent le bout du glacier, il est très-facile, par l'aspect du dépôt, de déterminer l'étendue sur laquelle s'exécute le mouvement dont il s'agit. Pour le glacier des Bois, la différence entre le plus grand et le plus petit avancement n'est que d'environ 150 toises. Recherchons maintenant la cause de ce mouvement. De prime-abord

ment. We see at first sight that it is entirely comprehended in those which occasion variations in the quantity of snow received upon the reservoir glaciers.

In fact, if they receive an additional quantity of rain, of snow, or of vapour, the flow is in proportion, and the stream glacier must advance a little farther into the zone of melting before it is destroyed; if, on the other hand, the reservoir glaciers receive less, the stream glaciers are melted before reaching the same point. Now we know that there is a great difference between different years in respect of the quantity of rain they bestow upon the earth; the glaciers also, therefore, must vary in bulk. The peasants of the valley of Chamouni say that heat causes the glaciers to increase. I should not be surprised if there were some truth in this assertion. When we call to mind that water has a melting power sixteen times as great as that of dry heat, it would follow that a summer of rain and continuous moisture must diminish the mass of a stream glacier much more rapidly than a summer of sunshine and drought, provided always that the rain were always warm, and did not pass into snow, as so often happens.

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on voit qu'elle est toute entière dans les causes qui peuvent faire varier la quantité des neiges survenues dans les glaciers-réservoirs.

En effet, s'ils reçoivent plus de pluies, de neiges ou de vapeurs, l'écoulement est proportionné, et avant d'être détruit, le glacier d'écoulement doit s'avancer un peu plus dans la zone de fusion; si, au contraire, les premiers reçoivent moins, les derniers sont fondus avant d'arriver au même point. Or, on sait que les années varient beaucoup pour la quantité d'eau qu'elles donnent à la terre; les glaciers doivent donc aussi varier dans leurs masses. Les paysans de la vallée de Chamonix disent que les glaciers croissent par la chaleur. Je ne serais point étonné qu'il y eût de la vérité dans cette assertion. En nous rappelant que l'eau a un pouvoir de fusion seize fois plus grand que la chaleur sèche, il s'ensuivrait qu'un été pluvieux et continuellement humide devrait diminuer la masse du glacier d'écoulement bien plus vite qu'un été de soleil et de sécheresse, pourvu cependant que les pluies fussent toujours chaudes et ne passassent pas à la neige, comme cela arrive si souvent.

CHAPTER XVI.

OF ANCIENT MORAINES.

HITHERTO I have only heard speak of the movement executed in a small number of years—of a movement whose alternations can be observed during the life of a man; but there are, besides, on the ground, or at least at a certain distance from the glaciers, indications of a movement executed at a time which is, perhaps, separated from us by a long series of ages. The facts are as follows:—On examining the land situated at the extremities of glaciers, and even at a pretty considerable distance in the prolongation of valleys, the upper parts of which are traversed by the ice, we see ancient *moraines* which have most assuredly been formed by the glacier, which is now at a distance from them more or less considerable, but nearly always great enough to suggest the conviction that the glacier never can return so far. In a paper published by M. Venetz, the engineer,

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CHAPITRE XVI.

DES ANCIENNES MORAINES.

Je n'ai entendu jusqu'ici parler que du mouvement qui s'exécute dans un petit nombre d'années, de ce mouvement dont les alternatives peuvent s'observer pendant la vie d'un homme; mais il y a en outre sur le sol, ou du moins à une certaine distance des glaciers, des indices d'un mouvement qui s'est exécuté dans un temps qui est peut-être séparé de nous par une longue suite de siècles. Voici les faits: en examinant les terres qui sont placées à l'extrémité des glaciers, et même à une assez grande distance dans le prolongement des vallées dont la partie supérieure est parcourue par les glaces, on aperçoit d'anciennes moraines qui ont été bien certainement formées par le glacier, qui maintenant s'en trouve éloigné d'une distance plus ou moins considérable, mais presque toujours assez grande pour faire croire que jamais le glacier ne pourra revenir jusque-là. Dans un Mémoire que M. Venetz, ingénieur, a

On the variations of temperature in the valleys of Switzerland, he refers to thirty-four glaciers of the Alps as having retired from their ancient positions, and as having left traces of their stay at a distance of a league, and often more, from the place where they now come to an end. We even find *moraines* in places from which the glaciers have entirely disappeared. As this phenomenon is of great importance in the history of the revolutions of the globe, I will give an idea of it by submitting to the notice of the reader the ancient *moraines* of the glacier of *Rossboden,* near the village of Simplon; they are the only ones that I have had the opportunity of observing for myself. M. Venetz has given a sketch of them, which appears to me to be perfectly accurate, and which I copy from his paper.

As we rise above the little village of *Anderegen,* which is built on ancient *moraines,* we trace with the eye three lines of *moraines* which have been successively abandoned by the glacier, which has retreated to a distance of 7,000 feet from that which is now the most remote from it. As it is generally supposed that these derelict *moraines* go back to a great antiquity, I

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publié *sur les variations de la température dans les vallées de la Suisse,* il cite 34 glaciers des Alpes qui se sont retirés de leurs anciennes positions, et qui ont laissé des traces de leur séjour à une lieue, et souvent plus, de distance de l'endroit où ils se terminent maintenant. On trouve même des moraines sur des lieux où les glaciers ont entièrement disparu. Comme ce phénomène est d'une grande importance pour l'histoire des révolutions du globe, je veux en donner une idée en mettant sous les yeux du lecteur les anciennes moraines du glacier de *Rossboden,* près du village du Simplon; ce sont les seules que j'aie été dans le cas d'observer par moi-même. M. Venetz en a donné un dessin qui m'a paru parfaitement juste, et que je copie, dans son Mémoire.

En s'élevant au-dessus du pétit village d'*Anderegen,* qui est bâti sur les antiques moraines, on suit de l'œil trois enceintes de moraines qui ont été successivement abandonnées par le glacier, qui s'est éloigné de 7,000 pieds de celle qui en est maintenant le plus écartée. Comme on suppose en général que ces moraines délaissées remontent à une grande antiquité, j'ai

was desirous of attempting to verify this opinion by a comparison of the space given up by the glacier in its retreat, with the time it appears to occupy in its retrograde movement. According to information obtained on the spot, this glacier, which continues to diminish, seems to have abandoned 100 feet of earth in ten years. As the sum total of its retreat is 7,000 feet, supposing that its pace was regular, we should have 100 : 7,000 : : 10 : 700 years—which would thus have been needed to bring about the change observable at the present day.

In the map accompanying M. Venetz's paper the ancient *moraines* are designated by the letters A, B, C, D, E, F, G. These *moraines* which formed a sort of inclosed work have been cut by the torrent which occupies the lower portion of the valley. From the point K, at which the glacier terminates at the present moment, to the point D, which it formerly reached, the distance is 7,000 feet.

All naturalists have observed that the glacier from which the Rhone makes its escape into the Valley of Conches, occupied in former times a space much more considerable than that which it now occupies. The

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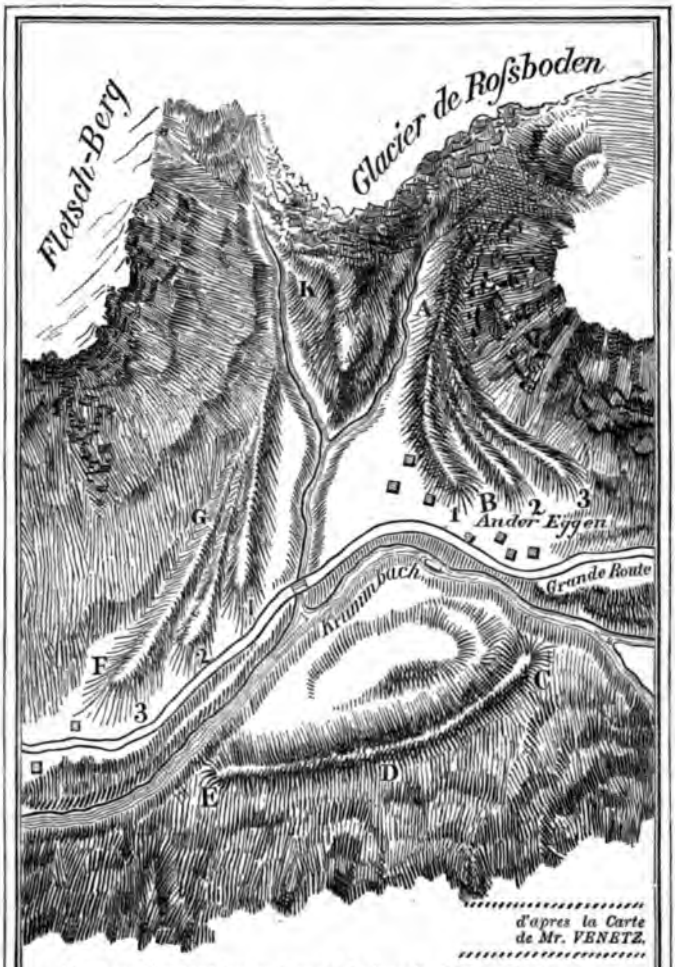
voulu essayer de vérifier cette opinion en comparant l'espace abandonné par la retraite du glacier, au temps qu'il semble mettre à son mouvement rétrograde. D'après des informations prises sur les lieux, ce glacier, qui continue à diminuer, semble avoir abandonné 100 pieds de terrain en 10 ans. Comme la totalité de la retraite est de 7,000 pieds, à supposer que sa marche fût régulière, nous aurions 100 : 7,000 : : 10 : 700 ans, qui auraient été nécessaires pour opérer le changement qui s'observe aujourd'hui.

Dans la carte qui accompagne ce Mémoire, les anciennes moraines sont désignées par les traces A, B, C, D, E, F, G. Ces moraines qui formaient une espèce d'enceinte, ont été coupées par le torrent qui occupe le fond de la vallée. Depuis le point K auquel se termine actuellement le glacier, jusqu'au point D où il arrivait autrefois, la distance est de 7,000 pieds.

Tous les naturalistes ont observé que la glacier d'où s'echappe le Rhône dans la vallee de Conches, a occupé jadis un espace bien plus étendu que celui qu'il occupe maintenant. Le



Carte représentant les anciennes Morênes du Glacier du Simplon.
K, *extrémité actuelle du Glacier.* D, *extrémité ancienne.*
A, B, C, D, E, F, G, *anciennes morênes du Glacier.*
1, 2, 3, *Morênes successivement abandonnées par le Glacier.*

ground it has abandoned is covered with a series of *moraines* extremely interesting to the observer. I shall transcribe the description of them given by M. Venetz in the paper already cited :—

"The *moraine* most remote from the glacier leans "against a rock, forming a hillock, on which are con- "structed the chalets of the upland pasture ground. "It displays a great width, with a height of about two "and twenty feet. From the inner edge of this first "line of works to the middle of a second we found a "distance of about thirty feet ; from this to another, "scarcely perceptible, forty-five ; thence to a larger one, "ninety ; from this fourth to a following one, about "eighteen feet high, two hundred and forty-three feet. "Close to the last there is a small one, which we "measured into the distance of the following one, which "is five feet high, and is situated at two hundred and "forty feet from the great one. On the right of the "valley, this *moraine* branches into three or four up to "about its middle. From this *moraine* to another, four "feet high, ninety feet. The latter forms a series of

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terrain qu'il a délaissé est recouvert d'une suite de moraines extrêmement intéressantes pour l'observateur. Je vais donner ici la description qu'en fait M. Venetz dans le Mémoire déjà cité :

"La moraine la plus éloignée du glacier s'adosse contre un "rocher, formant un monticule, sur lequel sont construits les "châlets de la montagne. Elle présente une grande largeur, "sur une hauteur d'environ vingt-deux pieds. Du bord "intérieur de cette première enceinte jusqu'au milieu d'une se- "conde, nous avons trouvé une distance de trente pieds ; de "celle-ci à une autre, presque imperceptible, quarante-cinq ; de "là à une plus grande, quatre-vingt-dix ; de cette quatrième a "une suivante, qui a environ dix-huit pieds de hauteur, deux "cent quarante-trois pieds. Tout près de celle-ci on en rencon- "tre une petite, que nous avons comprise dans la distance de la "suivante, qui a cinq pieds de haut, et se trouve à deux cent "quarante pieds de la grande. Sur la droite de la vallée, cette "moraine se divise en trois ou quatre jusque vers le milieu. "De cette moraine à une autre, de quatre pieds de hauteur, "quatre-vingt-dix pieds. Celle-ci forme une suite de moraines

"*moraines*, piled up in an irregular fashion one against "another for a length of three hundred and sixty feet, "rising, almost insensibly, to a height of twenty feet "and upwards. This assemblage of a quantity of "*moraines* describes an arc, and unites itself, on the "right, with the last, without reaching the foot of the "mountain. Here the Rhone escapes from the glacier, "crossing the last line of works which it has formed; "then it follows the preceding one to the middle of "the plain, where it cuts it, as it does all the others. "From the place where the Rhone crosses this heap of "*moraines* to the most recent *moraine* the distance is "three hundred feet. On the left of the centre of "the glacier, the last-mentioned *moraine* just gives "a glimpse of the fact that it had covered one "more ancient, inasmuch as the turf is still visible "upon it."

From all these observations some naturalists have concluded that these movements of the glaciers go back to a very high antiquity. Possibly this idea may arise from the fact that the nature and origin of stream glaciers had not been sufficiently examined. I will here bring together the different considerations to which

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"entassées irrégulièrement les unes contre les autres, sur une "longueur de trois cent soixante pieds, s'élevant presque "insensiblement à la hauteur de vingt pieds et plus. Cet "assemblage d'une quantité de moraines décrit un arc et se "réunit, sur la droite, à la dernière, sans atteindre le pied de la "montagne. Ici le Rhône s'échappe du glacier, en traversant "la dernière enceinte que celui-ci a formée; puis il suit la "précédente jusqu'au milieu de la plaine, où il la coupe comme "toutes les autres. Depuis l'endroit où le Rhône traverse cet "amas de moraines jusqu'à la plus récente, la distance est "de trois cents pieds. Sur la gauche du centre du glacier, "celle-ci laisse entrevoir qu'elle en avait couvert une plus "ancienne, puisqu'on y voit encore le gazon."

De toutes ces observations quelques naturalistes ont conclu que ces mouvements des glaciers remontaient à une très-haute antiquité. Peut-être cette idée vient-elle de ce que la nature et l'origine des glaciers d'écoulement n'avaient pas été assez bien examinées. Je vais réunir ici les différentes considé-

regard must be had before pronouncing a judgment on the age of the *moraines* which lie in front of glaciers.

Firstly. We have seen that the smallest modification accruing to the slopes of reservoir glaciers might cause notable changes in stream glaciers, by taking from the one to increase the others.

Secondly. If it is true that a great number of glaciers have retired, it is also true that several have encroached upon lands formerly remote from them. In several places in the Alps there were frequented passages, which are now blocked up by eternal snows. Glaciers have been formed, in recent times, on spots where there never had ever been any. The Glacier of Rothelch, which commands the new hospice of the Simplon, had no existence in 1732; which would seem to prove that these changes are due to accident rather than to general causes.

Thirdly. Moraines may have been formed much more rapidly in primitive times, when the mountains were less hardened, and before they had acquired the banks formed from their own *débris*, which now serve them as buttresses.

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rations auxquelles il faut avoir égard avant de porter un jugement sur l'âge des moraines qui devancent les glaciers.

1° On a vu que la plus petite modification survenue sur les pentes des glaciers-réservoirs pouvait causer des changements notables dans les glaciers d'écoulements, enlever aux uns pour augmenter les autres.

2° S'il est vrai qu'un grand nombre de glaciers se soient retirés, il est vrai aussi que plusieurs ont empiété sur des terres qui en étaient éloignées auparavant. Dans plusieurs endroits des Alpes il y avait des passages fréquentés qui sont maintenant obstrués par des neiges éternelles. Il s'est formé dans les temps récents des glaciers sur des lieux où il n'y en avait jamais eu. Le glacier de Rothelch, qui domine le nouvel hospice du Simplon, n'existait pas en 1732. Ce qui semblerait prouver que ces changements sont dus à des accidents plutôt qu'à des causes générales.

3° Les moraines ont pu se former beaucoup plus rapidement dans les premiers temps où les montagnes étaient moins durcies, et avant qu'elles eussent reçu ces talus formés de leurs propres débris et qui leur servent maintenant de contrefort.

Fourthly. The incessant crumbling away to which mountains are subject is considerable enough, at certain points, to render their loss of height perceptible in the short space of a man's life. The rocks which cumber the bottoms of valleys, those which are carried down into the plains by avalanches of earth—sand, gravel, earth, carried by water very far from its place of origin, constitute a sort of measure of the lowering of the mountains. The aiguilles of laminated rock found so frequently on crystalline mountains, are, as it were, surviving witnesses to the ancient elevation of the mountain chains. But is it not quite natural that the lowering of the mountains, the raising of the valleys, the destruction of the mountain peaks, should contribute to the diminution of the glaciers ?

Fifthly. The heightening of the soil in the bottoms of the valleys may, in the same way, have brought about sensible changes in the extent of glaciers ; for the mean temperature increases in proportion as the ground is brought to a uniform level, even when it remains at the same absolute height.

Sixthly. The destruction of forests must have had a

4° Les dégradations incessantes que subissent les montagnes sont assez considérables pour que, sur certains points, leur abaissement soit observable pendant le court espace de la vie d'un homme. Les rochers qui encombrent le fond des vallées, ceux qui sont arrivés jusques dans les plaines par les avalanches terreuses, les sables, les graviers, les terres que les eaux portent bien loin de leur origine, sont une espèce de mesure de l'abaissement des montagnes. Les aiguilles de roches feuilletées que l'on retrouve si fréquemment sur ces montagnes cristallines, sont comme des témoins restés de l'ancienne élévation des chaînes. Mais n'est il pas bien naturel que l'abaissement des montagnes, l'élévation des vallées, la destruction des cimes contribuent à la diminution des glaciers ?

5° L'exhaussement du sol dans le fond des vallées a pu de même apporter des changements sensibles dans l'étendue des glaciers ; car la température moyenne augmente à mesure que le sol s'uniformise, alors même qu'il reste à la même élévation absolue.

6° La destruction des forêts a dû avoir une très-grande

very great influence on the extent and even on the direction of glaciers. This is not the place in which to treat of this subject, which has already occupied the attention of a great number of naturalists; suffice it to remind the reader, that they are all agreed in asserting that the presence of forests lowers the temperature.

Seventhly. For the same reason, cultivation must also contribute to change the limit of snow and the extent of glaciers.

Eighthly. Lastly, if the valley which serves as the glacier bed is obstructed by matter, and the glacier cannot flow with ease, the ice heaps itself up so as to fill the valley; and as the causes which produce melting will be powerless as against too great a mass, the glacier will gain in surface, and will make *moraines* on all its edges; but if an inundation of any sort, an avalanche, for instance, should come and clear the valley, the ice will flow, will be borne rapidly forward, will leave *moraines* ahead, and little by little will retreat under the influence of the causes which produce melting.

I think that, with an attentive examination of localities, this last consideration would frequently be found applicable.

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influence sur l'étendue et même sur la direction des glaciers. Ce n'est pas ici le lieu de traiter ce sujet, qui a déjà occupé un grand nombre de naturalistes; il suffit de rappeler qu'ils sont tous d'accord pour affirmer que la présence des forêts fait baisser la température.

7° Par la même raison, la culture doit aussi contribuer à changer la limite des neiges et l'étendue des glaciers.

8° Enfin, si la vallée qui sert de lit au glacier est obstruée par les matériaux, et que les glaces ne puissent pas s'écouler facilement, elles s'amoncèlent de manière à la remplir; et comme les causes de fusion seront impuissantes sur une trop grande masse, le glacier gagnera en surface et fera des moraines sur tous ses bords; mais si une débâcle quelconque, une avalanche vient à ouvrir la vallée, les glaces couleront, se porteront rapidement en avant, y laisseront des moraines, et peu à peu se retireront sous l'influence des causes de fusion.

Je pense qu'avec un examin attentif des localités, on trouverait une application fréquente de cette dernière considération.

M. Godefroi, after having enumerated the new glaciers which have been formed in the Alps, and which have blocked up different passages which were formerly very practicable, whether between the different valleys of Switzerland, or between the Valais, Savoy, and Piedmont, inquires what can be the cause of this advance of the glaciers on the loftiest cols of the Alpine chain, whilst these same glaciers are evidently retreating at their lower part. I, too, have sought the solution of this double-headed problem, the two heads of which seem so diametrically opposed; I will give it in the following chapter.

CHAPTER XVII.

OF THE CHANGES WHICH HAVE TAKEN PLACE IN GLACIERS.

From the knowledge we have acquired of reservoir glaciers and stream glaciers, it is easy to understand that, in the forms of the higher rocks, changes may

M. Godefroi, après avoir énuméré les glaciers nouveaux qui se sont formés sur les Alps, et qui ont obstrué différents passages qui étaient autrefois très-praticables, soit entre les différentes vallées de la Suisse, soit entre le Valais, la Savoie et le Piémont, cherche quelle peut être la cause de cet avancement des glaciers dans les cols les plus élevés de la chaîne alpine, tandis que ces mêmes glaciers se retirent évidemment dans la partie inférieure. J'ai de même cherché la solution de ce problème à deux parties qui semblent si diamétralement opposées; je la donnerai dans le chapitre suivant.

CHAPITRE XVII.

DES CHANGEMENTS SURVENUS DANS LES GLACIERS.

Par les connaissances que nous avons acquises sur les glaciers-réservoirs et les glaciers d'écoulement, il est facile à comprendre qu'il peut survenir, dans la forme des rochers supérieurs, des

supervene, which will modify the respective quantities of ice which flow out by each channel. The sum total of the ice formed on the different ridges of Mont Blanc distributes itself, in order to descend into the region of melting, amongst all the channels, in proportions determined by the nature of the slope, the capacity of the ravines, the smooth or uneven nature of the surface which supports the ice, and a thousand other trifling circumstances which may escape our apprehension. Now, all these circumstances are of a variable nature. Thus, a rock which narrowed the communication between the reservoir glacier and the stream glacier may be disturbed, and borne away by the ice, and may increase its flow; thenceforward, the quantity supplied to the stream glacier being more considerable, it will encroach on the land which surrounded it. Similarly, it may happen that a rock travelling with the ice may be arrested in its course by impediments of ground, and may become itself an impediment to the flow; thenceforward, the glacier, being less abundantly fed, will retreat; but the ice must needs open another exit for itself, and perhaps form a new glacier. Lastly, we can understand

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changements qui modifieront les quantités respectives de glace qui s'écoulent par chaque canal. La totalité des glaces qui se forment sur les diverses crêtes du Mont-Blanc, se distribuent pour descendre dans la région de fusion entre tous les canaux, et dans des proportions qui sont déterminées par la nature de la pente, la capacité des couloirs, la nature lisse ou raboteuse de la surface qui porte la glace, et mille autres petites circonstances qui peuvent échapper à notre appréciation. Or, toutes ces circonstances sont de nature à changer. Ainsi un rocher qui rétrécissait la communication entre le glacier-réservoir et le glacier d'écoulement, peut être ébranlé, entraîné par les glaces, et augmenter leur écoulement; dès lors la quantité fournie au glacier d'écoulement étant plus considérable, il empiétera sur le terrain qui l'environnait. De même, il se peut qu'un rocher acheminé avec les glaces soit arrêté dans sa course par des obstacles de terrain, et qu'il fasse lui-même obstacle à l'écoulement; dès lors le glacier, moins abondamment alimenté, se retirera; mais il faudra que la glace s'ouvre une autre issue, et peut-être forme un nouveau glacier. Enfin, l'on conçoit que la

that the quantity of ice formed in the reservoir glaciers being always nearly the same, a change in a stream glacier cannot happen without its being reproduced in the opposite direction in one or more other glaciers: if one of them were to be entirely intercepted, others would increase in order to supply its place.

In fact, observation informs us of considerable changes which have taken place in the extent of certain glaciers. The Glacier des Bois, as M. de Saussure observes, has retreated about 150 toises; we can estimate its retreat by a great deposit, which in former times was a *moraine*, and which at the present day is covered with puny larches, but which the glacier no longer reaches at its periods of greatest increase.

The glacier has diminished proportionally throughout its whole extent. M. Godefroi is in error in saying that the Mer de Glace has received an augmentation from behind. It is a mistake, which is demonstrated by the two *moraines* which have been left precisely on the edges of the Mer de Glace, and at more than sixty feet above the ice, as it now is, and the *moraine* in course of formation.

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quantité de glace qui se forme sur les glaciers-réservoirs étant toujours à très-peu près la même, il ne peut survenir un changement dans un glacier d'écoulement sans que ce changement ne se reproduise à l'inverse dans un ou plusieurs autres glaciers: si l'un d'eux venait à être entièrement intercepté, d'autres s'accroîtraient pour le remplacer.

En effet, l'observation fait connaître des changements considérables survenus dans l'étendue de quelques glaciers. Celui des Bois, comme l'observe M. de Saussure, s'est retiré d'environ 150 toises; on peut en juger par un grand dépôt qui fut jadis une moraine et que est aujourd'hui couvert de chétifs mélèses, mais que le glacier n'atteint plus dans ses plus grands accroissements.

Le glacier a proportionnellement diminué dans toute son étendue. M. Godefroi s'est mépris en disant que la mer de glace avait reçu un accroissement postérieur. C'est une erreur qui est démontrée par les deux moraines qui ont été délaissées précisément sur les bords de la mer de glace, et à plus de soixante pieds au-dessus des glaces actuelles et de la moraine en formation.

Again, according to the observations of M. de Saussure, the glacier of Mont Dolent, in the Val Ferret, in former times filled the lower part of a valley, which it leaves at the present day uncovered. Its ice must have lost about two hundred feet in thickness. On the other hand, the Glacier de Triolet, which is in the same valley, seems to have been increasing considerably for a certain number of years past. These two glaciers start from the same part of the reservoir; up till 1721, the first appears to have been the more abundant; at that date, the fall of a rock, which took place on the 14th September, below the Triolet, facilitated the flow of the latter, which is still increasing, whilst the other is diminishing.

In the facts I have just pointed out, nature herself shows us her manner of action; all we have to do is to extend her action to all identical results. Observation sufficiently proves to us that the mountains are in process of exhaustion, are crumbling away; in proportion, therefore, as the rocks which served as ramparts to the reservoir glaciers are carried away by pressure or decomposition, the ice which is no longer held back spreads out on the flanks of the reservoir glaciers, and

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Encore selon les observations de M. de Saussure, le glacier du Mont-Dolent, dans la vallée de Ferret, remplissait jadis le fond d'une vallée, qu'il laisse aujourd'hui à découvert. Ses glaces ont dû perdre environ deux cents pieds d'épaisseur. Au contraire, le glacier du Triolet, qui est dans la même vallée, paraît s'accroître considérablement depuis un certain nombre d'années. Ces deux glaciers partent de la même partie du réservoir; jusqu'en 1721, le premier paraît avoir été plus abondant; à cette époque la chute d'un rocher qui eut lieu le 14 de septembre, au-dessous du Triolet, facilita l'écoulement de ce dernier, qui s'accroît encore, tandis que l'autre diminue.

Dans les faits que je viens d'indiquer, la nature nous montre elle-même sa manière d'agir; il ne s'agit que d'étendre son action à tous les effets identiques. L'observation nous prouve assez que les montagnes s'usent, se dégradent; à mesure donc que les rochers qui servaient de remparts aux glaciers-reservoirs, sont emportés par la pression ou par la décomposition, les glaces qui ne sont plus retenues s'épanouissent sur les flancs des glaciers-

thenceforward there is an extension of the upper glaciers, or even a formation of new glaciers; thenceforward melting is favoured by the increase of surface, and thenceforward the ice supplied to the lower stream glaciers being no longer so abundant, they retreat, and withdraw from the old *moraines*. The cause of this retrograde movement being continuous, it must be the same with the effect, and the lower glaciers will continue to diminish.

While considering the growth of the upper glaciers, M. Godefroi thinks he has grounds for concluding that the limit of perpetual snow has risen, without, however, any change having taken place in the mean temperature of the climate. This is no doubt a mistake on the part of M. Godefroi. It is not from the glaciers that we can estimate the position of the limit of eternal snow; this line passes exactly where the temperature is sufficient to melt each year the snow of the year; but the moment that we have to deal with a place where we find, not only the snow of the year, but also ice come from the upper regions, it is obvious that there we can no longer look for the limit of perpetual snow. Stream

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réservoirs, et dès lors il y a extension des glaciers supérieurs, ou même formation de glaciers nouveaux; dès lors la fusion est favorisée par l'augmentation de la surface, et dès lors la glace fournie aux glaciers d'écoulement inférieurs n'étant plus aussi abondante, ils se retirent et s'éloignent des anciennes moraines. La cause de ce mouvement de retraite étant continue, il doit en être de même de l'effet, et les glaciers inférieurs continueront à diminuer.

En considérant l'accroissement des glaciers supérieurs, M. Godefroi se croit autorisé à conclure que la limite des neiges perpétuelles s'est élevée, sans cependant qu'il y ait eu de changement dans la température moyenne du climat. Il y a sans doute méprise de la part de M. Godefroi. Ce n'est pas d'après les glaciers que l'on peut juger la position de la limite des neiges éternelles; cette ligne passe précisément où la température est suffisante pour fondre chaque année la neige de l'année; mais dès l'instant où il s'agit d'un lieu où non-seulement on trouve la neige de l'année, mais encore la glace venue des régions supérieures, on sent qu'il ne faut plus chercher dans ce lieu la limite

glaciers, therefore, may be formed without having any relation to the line of perpetual snow, and without any change having taken place in the general temperature.

It is well known that after the year 1811, which had been dry and hot, the glaciers diminished considerably; but after the rainy years of 1815, 1816, and 1817, the reservoir glaciers having received a considerable mass of water, the line of perpetual snow fell, and the stream glaciers followed the same course. At this date the Glacier of Distel, in the Valley of Saas, in Switzerland, came down nearly fifty feet in a single year.

These instances might be multiplied; but the position appears to me sufficiently self-evident.

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des neiges perpétuelles. Il peut donc se former des glaciers d'écoulement sans qu'ils aient aucun rapport avec la ligne des neiges perpétuelles, et sans qu'il se soit opéré aucun changement dans la température commune.

Il est reconnu qu'après l'année 1811, qui avait été sèche et chaude, les glaciers avaient considérablement diminué; mais après les années pluvieuses de 1815, 1816, 1817, les glaciers-réservoirs ayant reçu une masse d'eau considérable, la ligne des neiges perpétuelles s'est abaissée, et les glaciers d'écoulement ont suivi la même marche. A cette époque, le glacier de Distel, dans la vallée de Saas, en Suisse, descendit de près de 50 pieds dans une seule année.

On pourrait multiplier les exemples, mais la thèse me semble assez démontrée par elle-même.

CHAPTER XVIII.

ATTEMPTS TO CALCULATE THE AGE OF THE GLACIER DES BOIS.

From the time of M. de Luc, all geologists have sought to read the age of the world in the relations which must exist between the different revolutions which have succeeded one another on the surface of the globe. The sinking down of the mountain tops, the progressive elevation of the valleys, the alluvial deposits produced by the rivers at their entrance into lakes, or into the sea, the *débris* fallen from the mountains, and rising in banks along their sides, have furnished the author of the *Palingénésie* with arguments demonstrating, to his satisfaction, the youth of the world. It seems to me, that the consequences which have been attempted to be deduced from these different facts, are, in general, exaggerated. They ought to be confined to an epoch in the world's history, instead of being always applied to its origin. For example, from the progressive sinking of the mountains, we can, at the

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CHAPITRE XVIII.

ESSAIS DE CALCUL SUR L'AGE DU GLACIER DES BOIS.

Depuis M. de Luc, tous les géologistes ont cherché à lire l'âge du monde dans les rapports que doivent avoir entre elles les différentes révolutions qui se sont succédé sur la surface du globe. L'abaissement des cimes, l'élévation progressive des vallées, les atterrissements produits par les fleuves à leur entrée dans les lacs ou dans la mer, les éboulis tombés des montagnes et s'élevant en talus le long de leurs flancs, ont fourni des arguments à l'auteur de la *Palingénésie*, pour lui démontrer la jeunesse du monde. Il me semble que les conséquences que l'on a essayé de tirer de ces divers faits sont en général exagérées. Elles devraient être restreintes à une époque du monde, au lieu d'être toujours appliquées à son origine. Ainsi, par l'abaissement progressif des montagnes, on peut tout au plus

utmost, calculate the age of the mountains, but not that of the world, which may have existed a long time without mountains, or with mountains other than ours.

Several naturalists, since the time of M. de Saussure, have thought that probable conclusions with respect to the antiquity of the world might be drawn from the formation of the *moraines* which fringe the glaciers. It is this idea that I wish to submit to calculation, without, however, pushing the results too far. When it shall be demonstrated to me that the work of the glaciers, to produce its known effects, must have lasted from three to four thousand years, I shall conclude therefrom that the glacier has been in existence from three to four thousand years; but it would be more than rash to make the existence of the earth depend upon the existence of one or of several glaciers. The face of the earth is a record in which are written the numerous revolutions which have succeeded one another upon it; to know one of them is not to know them all.

The glaciers convey sand and rocks, which pile themselves up at its edges, and are there to be seen like ramparts; it is at the extremity of the glacier that this

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calculer l'âge des montagnes, mais non pas celui du globe, qui a pu exister long-temps sans montagnes, ou avec d'autres montagnes que les nôtres.

Plusieurs naturalistes, après M. de Saussure, ont pensé que l'on pourrait tirer sur l'antiquité du monde des inductions probables d'après la formation des moraines qui bordent les glaciers. C'est cette idée que je vais essayer de soumettre au calcul, sans cependant pousser trop loin les conséquences. Quand il me sera démontré que le travail du glacier, pour produire les effets connus, a dû durer trois à quatre mille ans, j'en conclurai que le glacier existe depuis trois à quatre mille ans; mais il y aurait plus que de la témérité à rattacher l'existence de la terre à l'existence d'un ou de quelques glaciers. La face de la terre est un registre où sont inscrites les révolutions nombreuses qui s'y sont succédé; en connaître une ce n'est pas les connaître toutes.

Les glaciers charrient des sables et des rochers qui s'entassent sur les bords et qui s'y présentent comme des remparts; c'est à l'extrémité du glacier que ce dépôt est le plus abondant; c'est

deposit is the most abundant; and this it is, that we will take for one of the bases of our calculation. If the total quantity of the deposit were known to us, with the partial quantity supplied to it each year by the river of ice, these two terms would give us that which represents its age; but it is obvious that we can form only approximate estimates, with respect both to the one and to the other; and the same calculation, made by twenty persons, would probably give twenty results, quite wide apart from one another. This is, to my thinking, a more than sufficient reason for not reposing absolute faith in any of them.

However, they give an idea of duration, which, from its shortness, is in harmony with all the other indications of the youth of the world of humanity, of the world as it has been set in order for the reception of man.

Instead of inquiring what quantity of matter the glacier pours year by year upon its terminal *moraine*, I have sought to discover approximately how much matter it contains upon its whole surface, and what time it takes entirely to renew itself. Knowing these two terms, and comparing the quantity contained on

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celui-là que nous prendrons pour l'une des bases de notre calcul. Si la quantité totale du dépôt nous était connue, avec la quantité partielle qui lui est fournie chaque année par le fleuve glacé, ces deux termes nous donneraient celui de son âge; mais on sent que l'on ne peut former sur l'un et sur l'autre que des appréciations approximatives; et le même calcul fait par vingt personnes, donnerait probablement vingt résultats tout-à-fait éloignés les uns des autres. C'est, selon moi, une raison plus que suffisante de ne croire à aucun d'une manière absolue.

Cependant ils fournissent une idée de durée qui, par sa briéveté, est en rapport avec tous les autres signes de la jeunesse du monde humanitaire, du monde tel qu'il a été rangé pour recevoir les hommes.

Au lieu de chercher combien de matériaux le glacier verse chaque année sur sa moraine inférieure, j'ai cherché à connaître approximativement combien il en contient dans toute sa surface, et combien il met de temps à se renouveler tout entier. Avec la connaissance de ces deux termes, et en comparant la quantité

the whole of the glacier with the mass of the deposit, I shall know how many times the glacier must have renewed itself, and consequently how long it must have existed.

Now, the materials accumulated at the foot of the glacier form a mass whose dimensions, reduced to means, are about:—

Length, ...	150 feet.
Breadth, ...	600 „
Depth, ...	100 „

(150 × 600 × 100 = 9,000,000 of cubic feet for the measure of the deposit.)

The rock-trains which I have described in Chapter IX., and which will be poured into this deposit, may be estimated as follows:—

Length, ...	30,000 feet.
Mean breadth, . . .	300 „
Mean depth, ...	½ foot.

which gives 30,000 × 300 × ½ = 4,500,000 cubic feet.

This quantity being contained twice in the quantity

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contenue sur la glacier total à la masse du dépôt, je saurai combien de fois le glacier aura dû se renouveler, et par conséquent combien il aura duré.

Or, les matériaux accumulés au bas du glacier forment une masse dont les dimensions, ramenées à des moyennes, sont environ:

Longueur, ...	150 pieds.
Largeur, ...	600 „
Profondeur, ...	100 „

(150 × 600 × 100 = 9,000,000 de pieds cubes pour la mesure du dépôt).

Les *traînées rocheuses* que j'ai décrites au Ch. IX, et qui vont se verser dans ce dépôt, peuvent être évaluées comme il suit:

Longueur, ...	30,000 pieds.
Largeur moyenne, ...	300 „
Profondeur moyenne, ...	½ „

Ce que donne 30,000 × 300 × ½ = 4,500,000 pieds cubes.

Cette quantité étant contenue deux fois dans la quantité du

of the deposit, we may conclude that the glacier has been twice renewed to form it. Let us see what length of time it takes to flow entirely out.

According to the observations I have cited in Chapter VIII., it advances 60 feet per annum, and according to the maps of M. de Saussure, its total length, reckoning from the upper glaciers which it receives, is 30,000 feet, which, divided by 60 feet (the length traversed each year), gives 500 years, and as it must have emptied itself twice only, it cannot have begun more than a thousand years ago.

I hasten to give warning that nothing is more uncertain than the result of these calculations. There is not one of the factors of the operation which may not be added to or diminished, without, perhaps, departing further from the truth than I have done. The mass of the deposit, supposing even that the dimensions indicated were exact, must have been much greater if there were added to it :—all the earth which water brings down, and all the blocks of rock it has rolled along the valley, and all that has passed from the rock-trains on to the banks of the glacier. Nor is the mass

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dépôt, nous pouvons en conclure que le glacier s'est renouvelé deux fois pour le former. Voyons maintenant combien de temps il met à s'écouler tout entier.

D'après les observations que j'ai citées dans le Chap. VIII, il avance de 60 pieds par année, et d'après les cartes de M. de Saussure, sa longueur totale, en comptant depuis les glaciers supérieurs qu'il reçoit, est de 30,000 pieds, qui, divisés par 60 pieds (longueur parcourue chaque année), donnent 500 ans, et comme il n'a dû se verser que deux fois, il n'aurait dû commencer que depuis mille ans.

Je me hâte d'avertir que rien n'est plus incertain que le résultat de ces calculs. Il n'est pas un des facteurs de l'opération auquel on ne pût ajouter ou diminuer sans peut-être s'éloigner de la vérité plus que je ne l'ai fait. La masse du dépôt, supposé même que les dimensions que j'ai indiquées fussent exactes, devrait être bien plus grande si l'on y ajoutait toutes les terres que les eaux entraînent et tous les blocs de rochers qu'elles ont roulés le long de la vallée, et tout ce qui a passé des traînées rocheuses sur les rives du glacier. La masse des

of the rock-trains brought up to its true value, inasmuch as I have counted only that which is on the surface, without keeping count of the matter contained in the interior of the ice. Lastly, as I observed in Chapter VIII., the velocity of the glacier, estimated at 60 feet, is absolutely unreliable, because my observations were not sufficiently numerous, and were made at one point only. Admitting, however, that these data were complete, they could prove but one thing, namely, the epoch at which the terminal *moraine* began to be formed; but before that time the river of ice descending much lower probably strewed the substances which it carries over other *moraines* which time has effaced.

However, to consider these results only in their most general form, we are forced to receive them as a proof that everything is recent in the production of the phenomena which we have just been examining. This conviction grows with the number of proofs. There are round about the Alps more than six hundred glaciers; almost all have *moraines*, whose mass corresponds with the quantity of matter carried by the glacier; but nowhere is the accumulation of these pro-

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traînées rocheuses n'est pas non plus élevée à sa valeur réelle, puisque je n'ai compté que ce qui est à la surface, sans tenir compte des matériaux contenus dans l'intérieur des glaces. Enfin, comme je l'ai dit dans le Chapitre VIII, la vitesse du glacier évaluée à 60 pieds n'est rien moins que sûre, parce que mes observations ne sont pas assez multipliées et n'ont été faites que sur un point. En admettant même que ces données fussent complètes, elles ne pourraient prouver qu'une chose, savoir, l'époque à laquelle la moraine inférieure a commencé à se former; mais avant le fleuve de glace descendant beaucoup plus bas, versait probablement les matériaux qu'il porte sur d'autres moraines que le temps a effacées.

Cependant, à ne considérer ces résultats que dans leur plus grande généralité, on est forcé de les recevoir comme une preuve que tout est nouveau dans la production des phénomènes que nous venons d'examiner. La conviction grandit avec le nombre des preuves. Il y a autour des Alpes plus de six cents glaciers; presque tous ont des moraines dont la masse correspond à la quantité des matériaux que charie le glacier; mais nulle part l'entassement de ce produit n'est assez grand

ducts large enough to carry the results of the calculation beyond historical times. There are relations between the form of the world as it is and the wants of man which tend to induce the belief that they go back to the same antiquity. The mind which should be disposed to plunge into imaginary theories as to the antiquity of man, will ever be brought low by the majestic agreement of nature, history, and revelation.

CHAPTER XIX.

FLOW OF WATER.

During the summer, water produced by melting is abundant, as it is easy to judge by the growth of the rivers which descend from snow-covered mountains. When we traverse the Glacier des Bois, at the bottom of each crevasse we admire a little stream, of fresh and limpid water, which appears to flow over a surface

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pour porter les résultats du calcul au-delà des temps historiques. Il y a entre la forme actuelle du monde et les besoins de l'homme des rapports qui tendent à faire croire qu'ils remontent à la même antiquité. L'esprit humain qui voudrait se lancer dans des systèmes imaginaires sur l'antiquité de l'homme, sera toujours atterré par le majestueux accord de la nature, de l'histoire et de la révélation.

CHAPITRE XIX.

ÉCOULEMENT DES EAUX.

Pendant l'été, les eaux de fusion sont abondantes, comme il est facile d'en juger par la crue des rivières qui descendent des montagnes couvertes de neiges. Quand on parcourt le glacier des Bois, on admire au fond de chaque crevasse un petit ruisseau d'une eau limpide et fraîche, qui paraît couler sur une surface

of emerald. These streams reach the edges of the glacier, lose themselves amongst the stones of the *moraine*, and unite again beneath the ice at the bottom of the hollow which contains it. Other streams reach the same destination by the openings which penetrate to the bottom of the glacier; and, lastly, springs and waterfalls fall also upon the bank of the icy river, and take the same direction; so that we are sure that there is a *subterraneous* river which flows beneath the whole extent of the glacier, and which comes to light only at its lower extremity. It would be curious to know the form and height of these vaults, which have never been resonant with aught save the roar of the torrent they conceal. Without absolutely disregarding the effect of central heat, the moist vapours must, as it seems to me, rapidly eat away the ice, and indefinitely increase this cavity; still, it may well be that it is not so, inasmuch as there have never been, so far as I know, an instance of the surface falling in upon the bottom; but that which is not seen on the Glacier des Bois is seen frequently enough elsewhere. In a paper published in 1825, M. Blanc, Canon of St. Maurice, in the Valais, mentions instances of catastrophes of this nature. Speaking of

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d'émeraude. Ces eaux arrivent sur les bords du glacier, se perdent à travers les cailloux de la moraine, et vont se réunir sous les glaces au fond de la cavité qui les contient. D'autres eaux y arrivent par les ouvertures qui pénètrent jusqu'au fond du glacier, et enfin des sources, des cascades tombent aussi sur la rive du fleuve glacé et prennent la même direction; de sorte que l'on est certain qu'il y a une rivière *souterraine* qui coule sous toute l'étendue du glacier, et qui ne se manifeste qu'à son extrémité inférieure. Il serait curieux de connaître la forme et l'élévation de ces voûtes qui n'ont jamais retenti que du fracas du torrent qu'elles cachent. Sans compter pour rien l'effet de la chaleur centrale, les vapeurs humides devraient ce me semble rapidement corroder les glaces et agrandir indéfiniment cette cavité; cependant il faut bien que cela ne soit pas, puisqu'il n'y a jamais eu, que je sache, des éboulements de la surface vers le fond; mais ce qui ne se voit pas au glacier des Bois, se voit ailleurs assez fréquemment. Dans un Mémoire publié en 1825, M. Blanc, chanoine de St-Maurice en Valais, cite des catastro-

the glaciers under which there are currents of water, he says—"As the vault is commonly very much flattened, "and very narrow, when the waters swell it is often "attacked all over by this liquid. Settlement is some- "times produced thereby, occasioning considerable "breaches. It was in this way that an immense breach "was formed last year in the glacier of Breney, which "has been nearly doubled this summer.

"These causes of destruction do not exist in places "where the glacier rests immediately on the ground. "It is also observed that when masses of snow or ice "cover up rivers, making a nearly equal thickness over "the banks and over the water, it is always over the cur- "rent of water that this snow and ice disappear first, and "often the whole river is exposed, whilst there are still "upon the banks considerable remains of snow or ice."

It is astonishing that, after having pointed out facts demonstrating so conclusively the power of effecting the fusion of ice possessed by water, the author of this paper should have written but to contest the efficacy of the means applied by M. Venetz to the destruction of a glacier.

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phes de cette nature. En parlant des glaciers sous lesquels il y a des courants d'eau, il dit: "Comme la voûte est ordinairement "très-surbaissée et très-étroite, dans les crues d'eau elle est "souvent atteinte toute entière par ce liquide. Il s'y produit "parfois des affaissements qui forment des brèches considérables. "C'est ainsi qu'il s'est formé l'an passé au glacier de Breney, "une énorme brèche qui a été presque doublée cet été.

"Ces causes de destruction n'existent pas dans les endroits "où le glacier repose immédiatement sur le sol. Aussi remarque- "t-on que quand des amas de neige ou de glace recouvrent des "rivières, en formant sur les bords et sur l'eau une épaisseur à "peu près égale, c'est toujours sur le courant de l'eau que cette "neige et cette glace disparaissent d'abord, et souvent toute la "rivière est mise à jour tandis qu'il y a encore sur les bords des "restes considérables de neige ou de glace."

Il est étonnant qu'après avoir indiqué des faits si concluants pour démontrer le pouvoir dont jouissent les courants d'eau pour opérer la fusion des glaces, l'auteur de ce Mémoire n'ait écrit que pour contester l'efficacité des moyens appliqués par M. Venetz à la destruction d'un glacier.

CHAPTER XX.

UTILITY OF GLACIERS.

THE intelligence which beams forth everywhere from the works of nature has placed its seal upon the glaciers as well as upon the fertile plain which is covered with harvest. The whole globe has been so arranged in its movements and in its forms as to preserve and to reproduce the life that the breath of Heaven has dropped into the world. Fire, air, and water are, with all organized beings, a primary condition of vitality, and the admirable organization which is ever reproducing them to meet wants ever springing afresh, reflects the Divine thought on created thought. The fire which accompanies the orb of day, the fire which bursts upon the earth rises to the heavenly bodies, and returns to us; the air, which is consumed, is absorbed and re-compounded; the water which journeys ceaselessly around the globe, is it not the flow and ebb of life? "Bless the Everlasting who

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CHAPITRE XX.

UTILITÉ DES GLACIERS.

L'intelligence qui reluit partout à côté des œuvres de la nature, a placé son sceau sur les glaciers aussi bien que sur la plaine fertile qui se couvre de moissons. Le globe entier a été disposé dans ses mouvements et dans ses formes de manière á conserver et à reproduire la vie que le souffle divin a laissé tomber dans le monde. Le feu, l'air et l'eau sont pour tous les êtres organisés une condition première de vitalité, et l'admirable combinaison qui les ramène toujours pour des besoins qui renaissent toujours, réfléchit la pensée divine sur la pensée créée. Le feu qui accompagne l'astre du jour, le feu qui jaillit sur la terre remonte vers les astres et revient à nous; l'air qui se consume, s'absorbe et se recompose; l'eau qui voyage sans cesse autour du globe, n'est-ce pas le flux et le reflux de la vie? "Bénissons l'Eternel qui a suspendu des amas d'eau au-dessus

has upheld the gatherings of the waters above the mountains, that by this ordering of His wisdom the earth might be watered," Ps. ciii. verse 13.

If the waters, which rain and the condensation of vapour bring down upon the earth, were to set out again at once to return into the bosom of the sea, the earth would pass suddenly from inundation to drought, and would remain often whole months without that element with which it cannot dispense for a single day. The Supreme Dispenser has provided for this necessity, and springs, rivulets, and rivers, images of His Providence, will be ever flowing. Two means have been set to work to retain the waters on the high places of the globe, and thence to let them flow, with a wise parsimony, so that the supply may be sufficient to outlast the dearth. The waters furnished by rain and by the condensation of vapour collect in the cavities of the mountains, escape by the fissures of the rocks, and take their flow along the valleys; or, again, the waters pour in abundance to freeze upon the culminating points of man's dwelling-place, and, gently melting through the dry season, maintain the springs and the rivers. Recent physicists

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des montagnes, afin que par cette disposition de sa sagesse la terre fût arrosée." Ps. 103, vers. 13 (*sic*).

Si les eaux que les pluies et la condensation des vapeurs apportent sur la terre se remettaient immédiatement en voyage pour rentrer dans le bassin des mers, la terre passerait subitement de l'inondation à la sécheresse, et resterait souvent des mois entiers sans cet élément dont elle ne peut se passer un seul jour. Le suprême ordonnateur a pourvu à cette nécessité, et les sources, les ruisseaux et les fleuves, images de sa Providence, couleront toujours. Deux moyens ont été mis en œuvre pour retenir les eaux sur les sommités du globe, et de là les laisser couler avec une sage parcimonie, afin que les provisions puissent suffire à la longueur de la disette. Les eaux des pluies et des vapeurs condensées se rassemblent dans les cavités des montagnes, s'échappent par les fissures des rochers, et vont couler le long des vallées; ou bien encore les eaux courent en abondance se durcir sur les points culminants de la demeure de l'homme, et en se fondant lentement pendant la saison de la sécheresse, entretiennent les sources et les rivières. Des physi-

have advanced the proposition that rain and the melting of snow play scarcely any part at all in the supply of springs, and that these are due entirely to the condensation of vapour. These cabinet naturalists have not beheld nature in her own home; would they come and pass some years in our mountains, they would see how great is their mistake. There is the place to which they ought to come to study all the phenomena which are connected with the natural flow of water. There is not a mountain which has not at its feet, or along its sides, a multitude of springs, to which it is in general easy to assign a definite origin. There are some which begin to flow some hours after rain, and which dry up more or less rapidly in proportion to their abundance; there are some which flow only during rain, because they have no reservoir to collect the waters; there are some which dry up after one, two, or three months of drought, according to the capacity of the reservoir which feeds them; but all begin to flow afresh only after rain, and they cease precisely at the time when the condensation of vapour must be most abundant. At the foot of mountains of perpetual

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ciens récents ont avancé que les pluies et la fonte des neiges n'étaient presque pour rien dans l'entretien des sources, et qu'elles étaient dues entièrement à la condensation des vapeurs. Ces naturalistes de cabinet n'ont pas vu la nature chez elle; s'ils venaient passer quelques années dans nos montagnes, ils verraient combien est grande leur erreur. C'est là qu'il faut venir pour étudier tous les phénomènes qui se rattachent aux écoulements naturels des eaux. Il n'est pas une montagne qui n'ait à ses pieds ou le long de ses flancs une multitude de sources dont il est pour l'ordinaire facile d'assigner l'origine. Il en est qui commencent à couler quelques heures après la pluie, et qui tarissent plus ou moins rapidement à raison de leur abondance; il en est qui ne coulent que pendant la pluie, parce qu'elles n'ont aucun réservoir pour réunir les eaux; il en est qui tarissent après un mois, deux mois, trois mois de sécheresse, selon la capacité du réservoir qui les alimente; mais toutes ne recommencent à couler qu'après les pluies, et leur cessation a lieu précisément dans le temps où la condensation des vapeurs doit être plus abondante. Au pied des montagnes de neiges perpé-

snow there are many springs which break out only in summer time, because they owe their origin, beyond a doubt, to the melting of the glaciers. To conclude, we have but to see the springs, the torrents, the rivers, during the season of heat and drought, to remain convinced that the glaciers are but the storehouses of foresight open to meet the wants of organized beings. "(Bless the Lord) who sendeth the springs into the valleys, which run among the hills," Ps. civ. verse 10.

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tuelles il y a beaucoup de sources qui ne jaillissent que pendant l'été, parce qu'elles doivent infailliblement leur origine à la fonte des glaciers. Enfin, il suffit de voir les sources, les torrents, les rivières pendant la saison des chaleurs et des sécheresses, pour rester convaincu que les glaciers ne sont que des magasins de prévoyance ouverts aux besoins des êtres organisés. "(Bénissons l'Eternel) qui a ordonné aux sources de couler au fond des vallées, et qui a prolongé leurs cours entre les sinuosités des montagnes." Ps. 103, vers. 11 (*sic*).

FIN.

FORBES AND DR. TYNDALL.*

[*Introductory Note.* When Dr. Tyndall's Article† appeared in the *Contemporary Review* for August last, several of those whom its contents affected were so distant that communication with them would have entailed very considerable delay. Lest the public should interpret such delay as an acknowledgment of inability to answer that Article (which was soon issued as a Pamphlet), Professor Tait wrote to *Nature* a short reply, which, by the courtesy of the Editor, was allowed to appear in that journal on September 11th. The contents of that reply need not be referred to for the moment, since the more important of them will presently be given at greater length. In the next number of *Nature* (September 18th) appeared a letter from Dr. Tyndall, containing little to the point beyond a number of assertions and negations, altogether unaccompanied by evidence to support them. Some of these we will consider along with his Article. So far, then, the case still stands open, nearly as it stood on August 1st; but there is one point of some little consequence, which requires a word or two. The Editor of *Nature*, in his impartiality, while complaining of being virtually forced to publish certain expressions of Dr. Tyndall's (two of the less characteristic of which have been since re-

* *Written (by arrangement with the Publisher) for the "Contemporary Review" of November 1873; but, after having been put in type and corrected for press, considered unsuitable for its pages by the Editor of that Journal.*

† *Principal Forbes and his Biographers.*

published with a view to their withdrawal) remarked that he had, "in the exercise of his undoubted editorial "rights, struck out" from Professor Tait's letter "the "equivalents" of such expressions. Considerable curiosity has since been manifested as to the nature of these "equivalents;" and we therefore print here, in its original form, *the single clause* of Professor Tait's letter which the Editor of *Nature* considered himself called upon to modify, and which he accordingly toned down, while giving the rest in its integrity. The clause was as follows:—"which, coming as it does from an "Author who, in the same work, treats of the relative "merits of such giants as Young and Fresnel, exhibits "an amount of ignorance and inaccuracy almost "inconceivable." This was prefixed to an extract from Dr. Tyndall's most recent popular scientific work; an extract given (not, as Dr. Tyndall says, "in mere "ignoble spite," but lawfully and logically) for the purpose of showing that too much weight ought not, without careful consideration, to be assigned to statements made by Dr. Tyndall on a scientific subject:—such as, for instance, some of the points at issue in the present discussion, in so far, at least, as it relates to glaciers and their theory.

But, just as we write, another actor has appeared upon the scene:—and with tremendous effect. The terrible words of Mr. Ruskin *(Fors Clavigera,* Letter 34)* with regard to Dr. Tyndall and his *Forms of Water,* will reach myriads of intelligent readers besides those who could otherwise be expected to interest themselves in a question involving (however remotely) scientific issues. Mr. Ruskin's admirable command of language, his clearness, impartiality, acuteness, and his exemplary firmness in declaring truth and doing justice, leave nothing to be desired.

Our excuse for in any way seeming to interfere with the welcome operations of so unexpected and so powerful an ally must be; first, that we have been personally attacked, and so have to defend ourselves as

* Reprinted in this work.—ED.

well as Forbes: second, that *Fors Clavigera* deals more fully with the moral than with the historical and scientific aspect of the question, while it is the latter aspect to which mainly we address ourselves. Its publication has, however, materially simplified our present task, inasmuch as it has rendered it quite unnecessary for us to refer further to Dr. Tyndall's obvious inconsistencies as to the class of persons whom he selects as an audience for his discussions of disputed points in science, and for his judgments of the relative merits of scientific men. It spares us also, to a great extent, the necessity for further allusion to the strange sayings and doings of M. Agassiz, for it has most summarily and effectually disposed of him and all his claims, in so far as they have any reference to Forbes.

Relieved of these burdens, we need not spend much time on what remains for us to do.]

For precision's sake, in answering Dr. Tyndall, we will arrange our remarks under the following heads:—

I. Were we justified in regarding Dr. Tyndall's *Forms of Water* as "reiterating" charges formerly made against Forbes?

II. Were we not, in consequence, bound to do something; and could we have done less than we did?

III. What we did do, and in what spirit we did it.

IV. Short account of the manner and matter of the controversy.

V. Analysis of Forbes' *Reply*, with remarks on some of Dr. Tyndall's comments and explanations.

VI. Dr. Tyndall's Article.

These we proceed to consider in order.

I. *Were we justified in regarding Dr. Tyndall's* Forms of Water *as reiterating charges formerly made against Forbes?*

Dr. Tyndall expresses astonishment that we should so regard the "blameless advent" of his "innocent," "modest," "unpretending," "boy's book of the "glaciers." Well:—in the very first notice of it which

we saw (*Nature*, March 27th, 1873), the reviewer (while otherwise, on the whole, commending the work) concluded by saying :—

" But surely it was not necessary to rake up again " the Forbes-Rendu controversy, nor to renew the " claims of Agassiz and Guyot."

Mr. Ruskin has recently expressed still more distinct convictions on the subject, so that we are by no means alone in our misunderstanding of Dr. Tyndall's intentions. Besides, Dr. Tyndall in part admits the charge himself. He asks Principal Shairp—

" Would it not have been, in a worldly sense, nobler " . . . to have suffered a little wrong . . . ?"

But, to let the reader judge for himself, we make a couple of short extracts (whose purport is in no way modified by the context) from the *Forms of Water*.

" Had he [Rendu] added to his other endowments " the practical skill of a land surveyor, he would now " be regarded as the prince of glacialists."

" I am here obliged to state facts in their historic " sequence. Professor Forbes, when he began his " investigations, was acquainted with the labours of " Rendu. In his earliest works upon the Alps he " refers to those labours in terms of flattering recogni- " tion. But though, as a matter of fact, Rendu's ideas " were there to prompt him, it would be too much to " say that he needed their inspiration."

Put these two passages into straightforward English, and they amount to this,—that Forbes, having the accomplishments of a land surveyor, and being acquainted with Rendu's work, put this and that together, and appropriated the discovery.

That this is Dr. Tyndall's meaning appears from his Article itself; for he says—

" He [Professor Forbes] was, I gather from the *Life*, " acquainted with the use of surveying instruments;

" and knowing roughly the annual rate of glacier
" motion, he would also know that, through the pre-
" cision attainable with a theodolite, a single day's—
" probably a single hour's—motion, especially in sum-
" mer, must be discernible."

On this passage we need only remark (1.) That no one had occasion to know better than Dr. Tyndall, long before the *Life* was published, how perfectly Forbes was acquainted with the use of surveying instruments; (2.) That the notion of detecting the hourly motion of a glacier was, and still is, one of Forbes' highest claims in this whole matter; for the idea, obvious as Dr. Tyndall now considers it, was in 1842 regarded by scientific men as novel and startling in the extreme. See, for instance, M. Studer's letter (*Life of Forbes*, p. 496). It was a very great, and perfectly original, discovery that the motion is continuous at all. Witness the favour in which the Dilatation theory was held.

In Forbes' *Reply* of 1860, he had minutely informed Dr. Tyndall of the nature and amount of his knowledge of Rendu's work, when he made his measurements in 1842. Dr. Tyndall deliberately ignores Forbes' plain statement of facts, and gives, in the second of the short extracts above, a version, of which it is not too much to say that it is utterly inconsistent with them. Is not this a serious personal charge against Forbes? Yet Dr. Tyndall says in his Article :—

" . . . while placing the Bishop in the position
" he merited, I went out of my way to point out that
" in all probability Principal Forbes required no such
" antecedent."

Here, again, while claiming credit for taking trouble in Forbes' behalf, Dr. Tyndall repeats his insinuation in a form, if possible, more than ever calculated to offend. He seems to have endeavoured, so far as in him lay, to throw into the shade even M. Desor, who

at his best, never advanced farther than saying (*Excursions et Séjours aux Alpes*, p. 444) :—

" . . . [Forbes] a *rediscovered*, après M. Rendu, " que la glace des glaciers a un haut degré de plasti- " cité, et pour peu qu'il continue à s'occuper des " glaciers, nous ne désespérons pas de le voir *redis-* " *cover* encore bien d'autres choses également inatten- " dues. Quel dommage que notre langue n'ait pas un " terme pour une innovation aussi remarquable !"

There are many passages of Dr. Tyndall's book, besides the two we have quoted above, which, more or less vaguely, sometimes by commission, sometimes by omission, insinuate charges against Principal Forbes. Such are, for instance, those concerning the use of the theodolite in glacier measurements. But it is not necessary to consider them farther. We have given enough of these " reiterated charges" to prove our case in full against the *Forms of Water*.

Yet, Dr. Tyndall, in his most impressive manner, says :—

" I therefore avoided all allusion to those sore per- " sonal dissensions (*sic*) which, to the detriment of " science and of men, had begun fifteen years prior to " my connection with the glaciers, and which have been " unhappily continued to the present time."

" . . . in writing my book I had no notion of " rekindling an extinct fire, or of treating with any- " thing but tenderness the memory of his [Principal " Shairp's] friend."

" Thus the attitude of a controversialist is once more " forced upon me."

And finally—

" I think it on every account deplorable that this " controversy should have been revived."

After what we have above proved, our only comment

on these passages is the very old, but never trite, line of Juvenal :—

"Quis tulerit Gracchos de seditione querentes?"

II. *Were we not, in consequence, bound to do something; and could we have done less than we did?*

To the first part of this question it would be impossible to reply otherwise than in the affirmative. Not to have taken notice of charges publicly made, at the very time that the *Life* was about to be published, would have been tantamount to, either (1.) Tacitly admitting that they were well founded and irrefragable; or (2.) Tacitly asserting that Dr. Tyndall's statements were not worthy of our notice, or of the trouble of answering them. The former alternative was, of course, absurd; and we fear that, much as the course we have taken has irritated Dr. Tyndall, the latter alternative would have irritated him still more.

To the second part of the question a somewhat more detailed answer is necessary, as Dr. Tyndall, in his Article, has gone out of his way to impute motives, and in so doing, to drag in matters which would seem to most people to have little to do with the question. It is quite true, as Dr. Tyndall reminds the public, that some ten years ago he was involved in a controversy with Sir William Thomson (who was originally announced by Mr. Macmillan as one of Forbes' *Biographers*) and Professor Tait; and that further, as he thinks it right to inform the public, "hostilities had honourably ceased," &c. But what has all this to do with our duty as biographers of Forbes? Does Dr. Tyndall imagine that a reconciliation, after a controversy, in which all the argument was on one side, while all the strong language and the verbosity were ranged on the other, is to shut for ever the mouths, both of victors and of vanquished, as regards criticism of one another's writings? From what he says one might almost be led to fancy that he acted on the feeling that, Forbes being dead, and a reconciliation of Forbes' (scientific) biographers with himself having been

effected, he might safely re-open his injurious charges! And he is incautious enough to add the following sentence, which might be interpreted as strongly supporting (by the words which we have italicised), such an hypothesis :—

" . . . the fire was not extinct; the anger of " former combats, *which I thought spent*, was still poten- " tial, and my little book was but the finger which pulled " the trigger of an already loaded gun."

Since these matters have been alluded to, it is well that the description of them should at least be made accurate; and, therefore, we may inform the public that if they will take the trouble to read the details of the " combats " referred to, which will be found in the *Philosophical Magazine* for 1863–4, they will perhaps be surprised to see that all the " anger" was, with the strong language, on one side; while recent events have shown that on that side it still occasionally manifests itself.

III. *What we did do, and in what spirit we did it.*

(*a.*) Principal Shairp's and Mr. Adams-Reilly's portions of the *Life* were printed off before Dr. Tyndall's work was published. There can, therefore, be no question as to these: further than the general one, whether, in writing them, the authors avoided as far as possible introducing controversial matter little relevant to their main object—the production of a consistent and intelligible biography.

In a letter to *Nature* (May 29th, 1873) Principal Shairp says :—

" . . . it was the desire of the biographers to " exclude, as much as possible, all controversial matters, " not from any doubt as to the justice of Forbes' " claims as a glacier discoverer, but in order, as far as " might be, to avoid strife. If they have not succeeded " in doing so as completely as they wished, this has not " been their fault. When the book was almost through " the press, they found themselves, by the appearance " of Professor Tyndall's work on the '*Forms of Water*,'

" constrained to depart somewhat from their original " intention, and to include two statements which " Forbes had written on the subject of his glacier dis- " covery, and which are now to be found in Appendix " A and Appendix B of his 'Life.' These contain the " gist of the whole question, as far as Forbes was " concerned. Neither the one nor the other has ever " yet been refuted in any point."

(*b.*) In his *Preface* Principal Shairp introduces the subject in the following words :—

" With these remarks this Preface might have ended. " It had been our hope that we might have been allowed " to tell our story, without reverting to controversies " which, we had thought, had been long since ex- " tinguished. But after most of these sheets were in " the press, a book appeared, in which many of the old " charges against Principal Forbes, in the matter of the " glaciers, were, if not openly repeated, at least not " obscurely indicated. Neither the interests of truth, " nor justice to the dead, could suffer such remarks to " pass unchallenged. How it has been thought best " for the present to meet them I must leave my friend " and fellow-labourer, Professor Tait, to tell. Without " pretending to judge of the details of controverted " questions, which belong to a field of study with which " I am unfamiliar, I desire here to express the absolute " faith which I, in common with all who really knew " Forbes, have in his scrupulous and chivalrous honour, " as well in every other matter, as in doing justice to " the claims of previous discoverers. Since the subject " has been re-opened, it is well that it should be sifted " to the bottom. The claims of Forbes we will [then] " gladly leave to the verdict of those who are competent " and impartial judges, in full confidence that—

" 'Whatever record leap to light,
He never shall be shamed.'"

On this Dr. Tyndall comments as follows :—

" That modest volume [*Forms of Water*] has, we are

" informed, caused an uncontemplated addition to be " made to the Life. . . ."

" There is, I submit, no colour of reason in such a " complaint, and it would never, I am persuaded, have " been made had not Principal Shairp and his col- " leagues found themselves in possession of a document " which, though published a dozen years ago by " Principal Forbes, was never answered by me, and " which, in the belief that I am unable to answer it, " is now reproduced for my confutation."

From these two passages we learn that Dr. Tyndall considers that we had determined beforehand to reprint Forbes' crushing *Reply*, and that we seized upon his *Forms of Water* as a welcome, though a totally inadequate, excuse for doing so. To this we simply give a flat denial: though, when accusations of this kind are flung about without even the semblance of a justification, it is perhaps best to leave them unnoticed.

(*c.*) We have already shown that Dr. Tyndall has, unwittingly he would make it appear, reiterated some of his charges against Forbes. It was necessary that he should be answered, and we found it simpler and easier, while we thought it more just to the accused, to reprint Forbes' own defence of himself, than to work into sheets ready for "press" a thread of incongruous and unpleasant material. Professor Tait's Chapters, therefore, stand as they were written; that is, with the barest possible mention of the fact that such controversies had been, and about what; and they give what we still consider to be an impartial (certainly not a too favourable) account and estimate of Forbes' services to science.

The following words were added by Professor Tait to his already finished chapters:—

" A popular work, the *Forms of Water, &c.*, just " published by Dr. Tyndall, reiterates an estimate of the " actual and relative originality, extent, and value of " Forbes' contributions to the theory of glaciers, so ut- " terly different from that contained in the preceding

" chapter as to render it imperatively necessary for me " to make a few additional remarks. I believe the " question to be one entirely of facts, not of opinions : " and I feel assured that the work referred to would " have elicited a prompt reply from Forbes had he lived " to see it.

" In proof of the general correctness of the view I " have taken above, and as the only approximation now " possible to the answer Forbes would probably have " given, I have reprinted (in the form of Appendices " A. and B. below), two most masterly papers of his, " which unfortunately had not a very wide circulation : " but which minutely detail his relations to Rendu on " the one hand, and to Guyot and Agassiz on the other. " Though the first of these has been published for " twelve years, and the second for thirty, no attempt " has ever been made to controvert or to answer either.

" Till it is shown that these papers, along with " others from which extracts have been made above, " are not the work of Forbes, in whose character un- " swerving rectitude was the grandest feature, I shall " continue to receive their contents as facts. From " these facts no conclusions are possible but those " drawn in the preceding chapter."

Surely nothing could be more brief or more temperate, considering the work on which the writer had been engaged, and the way in which he found the old charges repeated, twelve years after they had been refuted, and four years after Forbes' death.

In Professor Tait's letter to *Nature*, above referred to, he thus speaks of his own portions of the work :—

" I shall be obliged by Dr. Tyndall's pointing out to " me a single expression, in that part of Forbes' Life " which was written by me, which is calculated to give " him the slightest offence :—with the one exception of " a letter from Forbes, which was specially written for " publication : and which, for Forbes' own sake, I would " rather not have published. No doubt, he may be " annoyed by my saying that little has since been

"added to the observations made by Forbes on gla-
"ciers. That is a matter of opinion. I do not think
"that Dr. Tyndall has made any addition of conse-
"quence to our knowledge of glaciers, and I am sup-
"ported in this belief by many of the very highest
"authorities. But this is no charge against Dr. Tyndall.
". . . . The rupture of the truce, or 'peace,'
"whatever that may be, was the work of Dr. Tyndall
"himself—partly by his *Forms of Water, &c.*, mainly
"by his article in the *Contemporary Review*."

Professor Tait thus emphatically proves that he had no share in the rupture of the "peace;" although, as we have seen, it would be utterly unreasonable to expect that any such transaction could stand in the way of one's defence of an admired friend and instructor against the repetition, after his death, of charges which in his lifetime he had conclusively refuted.

IV. *Short account of the manner and matter of the controversy.*

Possibly Dr. Tyndall himself may not be able to state precisely either the date of origin, or the cause, of his obvious grudge against Principal Forbes. It existed, in full bud at least, as early as 1854, as may be seen by reference to the *Philosophical Transactions* of that year. The tone of Dr. Tyndall's communication there printed (about Forbes' speculations on the *Trevelyan Experiment*) is such as could not possibly be used except with regard to a man with whom the author felt it was hopeless to expect ever to be on terms of the slightest acquaintance. In that paper, as in everything else which he has since written about Forbes, Dr. Tyndall has exhibited extremely great skill in choosing precisely such forms of language, besides occasional charges of such a nature, and made in such a manner, as were calculated to produce the most exquisite possible torture in the mind of a scrupulously upright and high-souled man. As Forbes truly says of one of these

charges, with dignity thoroughly preserved under utterly unmerited accusations :—

"Now, an allegation that an author or observer has "suppressed his knowledge of the antecedent labours of "others in the same field, that he has even omitted "some facts, while he claims credit for candour by "citing others of less importance, or which bear less "directly upon his own claims to their discovery:— "such an allegation, I say, is an odious one, whether "made explicitly or by inevitable implication. It re- "quires to be openly met by the person whose "character is really in question much more than his "originality."

It is with reference to this charge, amongst others, that Dr. Tyndall actually says :—

"My critics, however, do not seem to understand "that for the sake of higher occupations statements "may be allowed to pass unchallenged which, were "their refutation worth the necessary time, might be "blown in shreds to the winds. Of this precise charac- "ter, I apprehend, are the accusations contained in the "re-published essay of Principal Forbes, which his "friends, professing to know what he would have done "were he alive, now challenge me to meet."

And he adds that he "avoids all imitation of the "depreciatory and even sneering tone with which "[Forbes'] essay opens"!

An able writer in the *Alpine Journal* (August 1873) has taken a view of the case which is likely to enlist considerably more sympathy than Dr. Tyndall's view. He says :—

"It is difficult to suppose that imputations affecting "personal honour would be so lightly made as they "often are, if their authors realised the exquisite pain "they are calculated to give to men of high and generous "natures. It is a great mistake to suppose that the

" mere consciousness of innocence is, or ought to be,
" enough to render them innocuous. The more finely
" organised the moral nature, the more keenly sensitive
" it often is to undeserved reproach. A security, by
" no means the least, for the maintenance of high
" character, is a jealous care for an unspotted reputa-
" tion. It will be an ill day for the world, when names
" of discredit can be flung about and glide, like water
" from a duck's back, unheeded and unfelt by those at
" whom they are hurled, and when a sensitiveness to
" assaults upon personal integrity shall come to be re-
" garded as a weakness, or held to imply a consciousness
" that they are in some degree deserved. To those who
" knew Forbes well, it seems a contradiction in terms
" to couple his name with the thought of scientific
" plagiarism, or anything else that is mean or dis-
" honourable ; but we lay no stress upon any such con-
" sideration in the present case ; the position of Forbes
" is impregnable upon the merits and the evidence, and
" needs no aid from witnesses to character."

So much for the *manner* of Dr. Tyndall's treatment of Forbes, in passing from which we may quote the following extremely true, as well as apposite, words, especially as they are from the pen of Dr. Tyndall himself *(Philosophical Magazine*, 1864, II.)

" . . . though there is a dignity in silence when
" exercised at the proper time and in the proper way,
" it is *not* dignity, nor even manliness, as defined in
" England, that permits a man to make an unwarranted
" accusation, and prevents him from retracting it after
" its injustice has been exposed."

The *matter* of the treatment may be put shortly, as follows. Dr. Tyndall, having previously read Forbes' writings, went to examine the Swiss glaciers, with the view of endeavouring to account for their veined structure by something analogous to the explanation of slaty-cleavage given by Sharpe and Sorby. The idea of this analogy, we may parenthetically remark, was expressed by Forbes at a very early period of his glacier investi-

gations. Dr. Tyndall's observations led him to form a theory of glacier motion, partially based upon a then imperfectly understood experiment of Faraday. To this theory he gave the name of *Fracture and Regelation* (a singular example of something akin to what logicians call a Cross Division); and Forbes writes, on its first appearance, as follows :—

"I had already read, rather cursorily, the account "of Dr. Tyndall's Lecture. . . . Altogether, it "seemed like Thomson's view and mine, stereoscopically "arranged, and illuminated by the Electric Light."

In order to show that this was something different (in more than name) from the *Viscous* theory of Forbes, Dr. Tyndall had often "to wrangle resolutely with the facts"; and also to raise, about the meaning of the word viscosity, a discussion, for an estimate of which we must refer the reader to Mr. Ruskin's letter. As he became better acquainted with all that Forbes had done (especially after the publication of the *Occasional Papers*, the Preface to which is a most particularly remarkable and valuable document), Dr. Tyndall found less and less difference between his own theory and that of Forbes; and so at last it came about that a keen and well informed onlooker, the late Dr. Whewell, wrote (in 1859) to Forbes :—

"In the meantime you see that your discoveries have "passed from the stage when people say they are not "true, to the next stage, when people say they are not "new; and the truth of your theory is allowed."

This was written about the period when Dr. Tyndall "discovered," in Rendu's work, those passages of so "much greater importance" than those quoted by Forbes.

Speaking of the various (then) recent attacks which had been made on Forbes and his theory, especially in Reviews and Journals, M. Studer writes to him in 1863 :—

"En tout cas, ces misérables attaques ne serviront

" qu'à rappeler vos grands et reconnus mérites à un
" public qui, de nos jours où tout se presse, oublie
" trop vite."

We need not lengthen out this brief notice of an instance of what occurs in all mundane affairs frequently enough to have but little interest except to the actors, fortunately not frequently enough to become commonplace. All we need do, to conclude effectively this portion of our article, is to put beside one another two quotations from the *Forms of Water*, the first of which, in spite of the introductory phrase, we have had to correct (as shown by the square brackets) by altogether changing one important word, and by inserting two others.

" 406. The theory advocated by Professor Forbes
" was enunciated by himself in these words:—'A
" 'glacier is an imperfect fluid, or [a] viscous body, which
" 'is urged down slopes of [a] certain inclination by the
" 'natural [mutual] pressure of its parts.'"

" 424. The gist of the Regelation Theory is that
" the ice of glaciers changes its form and preserves its
" continuity under *pressure* which keeps its particles
" together. But when subjected to *tension*, sooner than
" stretch, it *breaks*, and behaves no longer as a viscous
" body."

Mr. Ruskin says:—

" Professor Tyndall knew perfectly well that Forbes
" was aware of the difference between ice and glue,
" without any need for experiments on them at the
" Royal Institution."

On the copy of the *Forms of Water* from which we have just made extracts, we find the following pencil note:—

" It appears, then, that the addition made by Dr.
" Tyndall to Forbes' theory is that ice cracks under
" tension sufficient to crack it!"

The attack to which Forbes' *Reply* is an answer was

contained mainly in Dr. Tyndall's *Glaciers of the Alps*, published in 1859. Forbes complains, with what justice we shall presently see, that both his work and that of Rendu are misrepresented by Dr. Tyndall; the merits of the one being as far as possible minimised, while its slightest slips are held up as grave blunders; the other having the advantage of a treatment which exalts even its barest guesses into matters of high scientific value, and leaves its numerous inaccuracies, and even blunders, unnoticed.

Though no one would gather it from Dr. Tyndall's Article, this is one of the main points of the *Reply*, the other being a refutation of the charge that Forbes had not done justice to Rendu; but the *Reply* happens to contain also some countercharges (almost or altogether independent of the other portions) against Dr. Tyndall. It is to these, almost to these alone, that Dr. Tyndall has confined himself in the August number of this *Review*. Thus, his article cannot be considered as, *in any sense whatever*, an answer to Forbes' masterly document, of the contents of which we proceed to give an account.

V. *Analysis of Forbes'* Reply,* *with remarks on some of Dr. Tyndall's comments and explanations.*

As this document is a long one, because thoroughly exhaustive in its treatment, it is to be feared that few, except those most interested, have taken the trouble to read it through with care; especially as its cold, rigorous, logic is in such direct contrast to the easy, because reckless, flow of, for the most part, unsupported assertion which is one distinguishing feature of the argument (!) on the other side.

Though, as we saw above, Dr. Tyndall has spoken of its "depreciatory and even sneering tone," though he says "it was obviously written under feelings of "great irritation," and though (we may parenthetically allow) it was certainly written in consequence of persistent and unmerited misrepresentation, amounting

* Reprinted as Appendix A. in the *Life of Forbes*.—ED.

almost to persecution, the unbiassed reader will find in it no undignified word—nothing that the writer could by possibility have wished to modify or retract had he been now alive to defend himself. We regret that considerations of space render it impossible to do justice to it here by giving such full extracts as would be desirable, but we recommend every one who wishes to form for himself an opinion on the merits of this question, to read it carefully through; to compare it in its calmness, its dignity, its thoroughness, its completeness of proof for every assertion, and its obvious straightforwardness and single-mindedness, with anything and everything that has been written on the other side. If readers could only be induced to do this, Forbes would need no defenders.

Forbes begins by referring to Dr. Tyndall's various Lectures and Papers upon glaciers from 1856.

"I could not fail," he says, "to observe that Pro-
"fessor Tyndall, in the warmth of pursuit incident to
"a new inquiry, had not, in the first instance, ap-
"prehended the full import of what had been done
"or asserted by me, and that he, not unnaturally,
"attached great, and I might think undue, importance
"to the observations which two or three brief, though
"actively employed, visits to the glaciers had enabled
"him to make. Perhaps I also thought that Professor
"Tyndall unnecessarily enhanced the distinctions which
"he conceived to exist between his views and my own,
"even where he had adequately studied the latter."

How true all this is, and how clearly Principal Forbes apprehended the nature of the attack which was in preparation, will appear presently. There is, however, no "sneer" here, nothing but an intimation, of the most delicate yet most unmistakable kind, that the tactics of his adversary had been seen through.

"Perhaps I should not have thought myself war-
"ranted in now departing from my previous course
"[steadily avoiding controversy] in this matter, but

" should have left any outstanding differences between " Professor Tyndall and myself to be calmly decided " by an impartial public, had it not been for one section " of his new work, which is headed *Rendu's Theory.*

" In the course of these few pages, Professor " Tyndall conveys to his reader the apprehension that " the memoir of Monseigneur Rendu on the Glaciers " of Savoy has been almost entirely overlooked by " English writers and readers on this subject: that the " descriptions of it have been inaccurate and even " deceptive, the extracts partial and not characteristic, " so that when, after several years of study of the " science of glaciers, his own attention was distinctly " called by a Swiss friend to Bishop Rendu's work, he " was surprised to find evidence of extensive knowledge, " close and accurate reasoning, and an extraordinary " faculty of observation; together with a constant effort " after quantitative accuracy, and 'a presentiment con- " 'cerning things as yet untouched by experiment which " 'belongs only to the higher class of minds.' Nor was " he less struck to find that the memoir contained pas- " sages of 'cardinal import' which previous writers had " 'overlooked,' and that it should devolve on himself " to call attention to them 'nearly twenty years after " 'their publication.'"

" Whether these merits of Bishop Rendu had really " been overlooked, as is here supposed—how far the " statements of 'cardinal import' referred to had been " knowingly or otherwise allowed to pass into forget- " fulness, and required to be revived after twenty years' " oblivion—I will presently endeavour to show. But " I must first state why I feel my credit involved in " these allegations, so as to induce me to withdraw from " the neutral attitude which I have generally adopted " towards Professor Tyndall's criticisms."

Next comes his clear summary of Dr. Tyndall's insinuations against his honesty in the matter of quotation from Rendu. We have seen above how he speaks of this "odious" allegation: and we may show, in passing,

by a short extract (from a letter of 1859) the opinion of Sir William Thomson. He says :—

"I cannot find words strong enough to express the "indignation I feel that such a charge as having 'done "'scant justice to Rendu' should have been made "against Professor Forbes. Nothing could be more "untrue. . . ."

Forbes next makes a few remarks on historical criticism in scientific matters, showing how the history of science would be made a maze of mingled truth and fiction if mere *isolated quotations* were to be taken as expressing an author's opinion on, or knowledge of, a subject.

"Professor Tyndall has treated Rendu's happy sug- "gestions in this spirit, and consequently claims for him "the parentage of every idea which, thrown out by him, "has since been proved to be true, while he casts a veil "over his less fortunate conjectures.

"He has treated my writings in precisely an oppo- "site spirit. He forgets that when my labours com- "menced I found *no single precise or quantitative fact* "respecting glaciers established in a reliable manner, "and that the whole weight of scientific authority was "then ranged on the side of one or other of two theories "of glacier motion, neither of which is now considered "worth refuting. As an example of the minuteness "of Professor Tyndall's criticism when my *Travels in "the Alps* are concerned, he has thought it worth while "to signalise *three times*, in as many different publica- "tions, the venial error of the True North being set "off on the compass-card of my Map of the Mer de "Glace on the wrong side of the *Magnetic* North, ac- "cording to which (as it is stated in the text) the map "has been laid down. [The magnetic variation is also "correctly stated in the text (p. 123, 1st edit.) at 19° "W.] Yet he allows that the error was corrected by "myself nearly ten years before he had any chance of "detecting it."

Principal Forbes then proceeds to the other part of the main work of his *Reply*. He divides it into two heads, briefly summed up in the following queries:—

"1. Whether the character given by me of Rendu "and his theory was so indefinite as to leave it to "Professor Tyndall to proclaim his merit for the first "time.

"2. Whether my citations from Rendu were not only "different from those made by Professor Tyndall, but "whether they omitted matter of *much greater import-* "*ance* than they included, and, by suppression, were "calculated to mislead."

To these he adds a countercharge in the form of a third query; and the reader is requested particularly to remark that it is to this issue alone that Dr. Tyndall attempts to reply.

"3. Whether the context of the passages cited by "Professor Tyndall from my work, and from that of "Rendu, does not affect or modify their significance."

The passages cited by Dr. Tyndall from Rendu are alluded to in what follows as the *First* and *Second Extract*. They are given in pp. 186, 189, below.

No. 1 of the above queries is exhaustively treated, and its discussion involves, amongst other matters of especial value as concerns the present controversy, that minutely detailed account of the difficulties Forbes encountered in endeavouring to procure the work of Rendu, to which we alluded in our first section. The whole passage is much too long for our pages, and to make extracts from so compact and connected a piece of argument would be only to weaken it. Suffice it to say that it completely and triumphantly answers query No. 1, above, in the negative: and that Dr. Tyndall is probably of this opinion, for, with the exception of his insinuation that Forbes was *acquainted* with Rendu's work in 1842 (an insinuation here shown to be utterly baseless), he has conveniently left this portion of the *Reply* altogether unnoticed.

No. 2 is very easily answered, also in the negative. Principal Forbes has already, in discussing No. 1, collected all his numerous and telling quotations from Rendu's work, and many of his allusions to its contents: and when we compare with these the "others of much "greater importance, which have hitherto remained un- "known in this country" and which Dr. Tyndall claims to have "discovered," it is certainly not at all obvious in what the greater importance consists. So little, indeed, is it obvious that even now, with the benefit of all Dr. Tyndall's further explanations, we do not see it. Perhaps Dr. Tyndall, should he again revert to this subject, may condescend to point out to what he refers.

Forbes, feeling the same difficulty, was obliged to make this portion of his *Reply* much longer than the importance of the passages quoted would seem to require. As regards the *First* of Dr. Tyndall's *Extracts* from Rendu, Forbes seems to have imagined (with what reason we shall presently see) that it was quoted for its bearing upon the greater central motion of a glacier, and to this he directed his answer. Dr. Tyndall now tells us that it was not so, and that the important matters were :—the value of Rendu's attempts to obtain (from guides !) an estimate of the rate of motion of the Mer de Glace, and the question whether Forbes "was entitled to conclude from the fact of different "velocities having been assigned to different glaciers, and "even to different points of the same glacier, that these "velocities, *because they thus differed*, were incorrect." Happily, Forbes seems to have been well acquainted with his antagonist's strategy, for in § 6 of his *Reply* (which immediately follows his remarks on the passage just referred to) he minutely examines the trustworthiness of the estimates of the annual amount of glacier motion (including those of Rendu) which had been made previous to his own measurements. This section, also, is much too long for quotation in full, and to extract from it would be to spoil it, but we can assure the reader that (if he will take the pains to go through it carefully) he will very soon see how complete and how

cogent it is :—and perhaps also will get a notion of why Dr. Tyndall has thought it prudent to make no reference to it whatever.

Dr. Tyndall's *Second Extract* from Rendu is one in which the resemblance between the Mer de Glace and a river is gone into with some detail ; but, as Forbes says, Basil Hall and others (to whom Dr. Tyndall does not refer) had done much the same thing before, and that, what was really wanted in this matter was *proof*, not *theory ;* and Forbes also shows that he had himself already given sufficient extracts to this particular effect from Rendu. He concludes his remarks on No. 2 with the following words :—

" I have shown, by extracts from my own writings, " that, in both these respects, I have given full credit " to Rendu for his just anticipations. But I have also " had to show that the grounds of his belief were in- " adequate, as they were also unsatisfactory to his con- " temporaries ; that they relied, on the one hand, on " reported estimates of velocity, at best, vague, pro- " bably erroneous ; and, on the other hand, on a fal- " lacious observation, which, if made aright, should " have led the author to an *opposite* result. That thus " the claim of Rendu, viewed by the light of Professor " Tyndall's extracts, amounts to no more than I had " previously cordially admitted, and had also been (I " may say) the first to proclaim,—that of having made " a sagacious anticipation of a true theory from limited " observations of no great precision."

We must return again to the clause which contains the italicised word *opposite.*

No. 3 is, for the moment, the most interesting, because it is upon Forbes' answer to this that Dr. Tyndall has exercised all his powers of " neck-breaking." Now, it is obvious at a glance that this is, so far as Forbes at least is concerned (and *his* credit is our main object at present), of little or no consequence. Dr. Tyndall, on the other hand, from his own point of view, no doubt naturally looks upon it as the most important of the

three queries. For here it is not Forbes, but Dr. Tyndall himself, who is on his defence: and, however it may be settled, Forbes cannot lose at all, though Dr. Tyndall may suffer considerably.

The question is, whether the context of certain passages cited by Dr. Tyndall from Forbes, and from Rendu, does not affect or modify their significance.

The following passage is from Dr. Tyndall's *Glaciers of the Alps:* the *italics* and CAPITALS in the portion translated (!) from Rendu are Dr. Tyndall's. This portion is referred to as the *First Extract.*

" ' . . . *The enormous difference between both*
" ' (sic) *results arises from the fact that the latter ob-*
" ' *servations were made at the centre of the glacier,*
" ' WHICH MOVES MORE RAPIDLY, *while the former were*
" ' *made at the side where the ice* IS RETAINED BY THE
" ' FRICTION AGAINST ITS ROCKY WALLS.' [Rendu, p. 95.]

" An opinion, founded on a grave misapprehension,
" which Rendu enables us to correct, is now prevalent
" in this country, not only among the general public,
" but also among those of the first rank in science.
" The nature of the mistake will be immediately appa-
" rent. At page 128 of the 'Travels in the Alps,' its
" distinguished author gives a sketch of the state of
" our knowledge of glacier-motion previous to the com-
" mencement of his inquiries. He cites Ebel, Hugi,
" Agassiz, Bakewell, De la Bèche, Shirwell, Rendu,
" and places them in open contradiction to each other.
" Rendu, he says, gives the motion of the Mer de
" Glace to be '242 feet per annum; 442 feet per
" ' annum; a foot a-day; 400 feet per annum, and 40
" ' feet per annum, or, *one-tenth* of the last!' . . . .
" and, he adds, 'I was not therefore wrong in supposing
" ' that the actual progress of a glacier was yet a new
" ' problem when I commenced my observations on the
" ' Mer de Glace in 1842.'"

Dr. Tyndall here quotes, against one another, passages from Rendu and Forbes. Into the former he introduces *italics* and CAPITALS, which are not in the

original and which can have no conceivable intention other than that of laying especial stress on the assumed fact that Rendu had pointed out that the centre of the glacier moves more rapidly than the sides, and that Forbes had not given him credit for this anticipation. Dr. Tyndall puts no capitals into his quotation from Forbes, but he omits as superfluous (placing four dots [. . . .] instead of it) one half of a sentence. The reader will be surprised to find that the omitted half sentence runs as follows :—

" . . . . or *one-tenth* of the last!—a difference " which he attributes to the different rates of motion " of the centre and the sides. (*Mém. de la Société " Académique de Savoie*, X. 95.)"

This portion of Forbes' *Travels* (with its reference to the very page of Rendu's work), thus pointedly omitted by Dr. Tyndall, contains *precisely* that statement which (by employing small CAPITALS in his *First Extract* from Rendu) Dr. Tyndall points out as one of those of "cardinal import" which it was left for him to "discover." Forbes calmly remarks :—

" I cannot but look upon this suppression of the end " of a quoted sentence, including the very point under " discussion, as an evidence of strong prejudice in the " writer, against which I feel myself called upon to " protest."

Dr. Tyndall, on the other hand, says :—

" The whole Reply betrays a state of mental exacer- " bation which I willingly left to the softening in- " fluence of time, and to which, unless forced to it, I " shall not recur."

The comparison of these two passages irresistibly reminds us of one of Leech's most effective scenes of real life :—

Old Gentleman (politely). 'Oh, Conductor! I shall " feel greatly obliged to you, if you would proceed,

" for I have an appointment in the Strand, and I am
" afraid I shall be too late !"

Conductor (slamming the door). " Go on, Jim !
" here's an old cove a cussin' and a swearin' like any-
" think ! ! !"

Dr. Tyndall, it is true, gives most elaborate reasons for his having suppressed the above-quoted passage. They are to some extent founded upon the occurrence of the note of exclamation (!) used by Forbes ! But he has apparently not noticed that, in § 6 of Forbes' *Reply*, above referred to, this note of admiration is explained, and along with it (as if by prescience) a second to which also Dr. Tyndall refers : — or, more probably, Dr. Tyndall, having seen this explanation, has thought it advisable for his case to pass it by in silence. Dr. Tyndall, as a rule, seems to rely too much upon a notion that his readers have not carefully read the passages he so triumphantly represents himself as refuting. This comforting assurance will not long remain to him. Rendu's work will soon be accessible to all ; and the *Reply* with which we are at present dealing forms Appendix A of Forbes' *Life*. It is to be particularly observed that, in all this controversy, Principal Forbes, though a lawyer, does not indulge in any special pleading ; he gives fully both sides of the case before he draws his inferences, and thus wins the confidence of the really intelligent reader.

When Dr. Tyndall next gives us a microscopic instalment of his defence, we commend earnestly to him § 6 of Forbes' *Reply, with its foot-notes,* as a portion which we consider (while still wholly unanswered) even more damaging to his case than almost any other portion, crushing as they all are. Forbes, indeed, says that this § 6 " embraces the real gist of the matter."

As regards the bearing of Forbes' query No. 3 upon Dr. Tyndall's *Second Extract* we have some difficulty : —not on account of Forbes, but on account of Dr. Tyndall. Dr. Tyndall takes it first in his Article, no doubt in order that he may have the benefit of what he

considers his triumphant reply to Forbes' charge in this case to help him over his difficulties with respect to the *First Extract*, which we have just seen to be so great. Here, however, we must allow that he does make out what certainly appears to be a very strong case; but, unfortunately for him, the stronger it is the worse for himself and for his *Glaciers of the Alps*. The matter stands thus :—

Extract from Rendu, restored to the original French :—

"Ce n'est pas tout, il y a entre le Glacier des Bois et "un fleuve une ressemblance tellement complète qu'il est "impossible de trouver dans celui-ci une circonstance qui "ne soit pas dans l'autre. Dans les courants d'eau la "vitesse n'est pas uniforme dans toute la largeur ni dans "toute la profondeur; le frottement du fond, celui des "bords, l'action des obstacles, font varier cette vitesse, qui "n'est entière que vers le milieu de la surface."—RENDU, p. 96.

Principal Forbes points out that if Dr. Tyndall, instead of terminating this *Extract* from Rendu with four dots (. . . .), had completed the passage, he would have shown Rendu relying (for a proof of the greater central motion) upon an observation, which, rightly interpreted,* should have given the very opposite of the desired result. In fact, Rendu goes on to say :—

"Or, la seule inspection du glacier suffit pour prouver "que la vitesse du milieu est plus grande que celles des "rives. La surface entière est coupée par des crevasses, "qui sont en général transversales à sa direction. Si le "mouvement était le même dans toute la masse, ces cre- "vasses, qui coupent la surface en ondées parallèles, for- "meraient une ligne droit que serait toujours à peu près "perpendiculaire aux deux rives; mais il n'en est point "ainsi; la ligne générale est une courbe dont la convexité "s'avance vers le bas de le vallée, ce qui ne peut être at-

* For the words "rightly interpreted," here used, the following ought to be substituted :—"If extended to other glaciers, or even to other parts of the same glacier." *Life of Forbes*, p. 539.—ED.

"tribué qu'à l'excès de vitesse que les glaces ont sur ce "point."—RENDU, *Théorie*, pp. 96, 97.

The question now turns upon the sense in which Rendu uses the word *crevasse*. This is an interesting, and to us a novel question; but, as will be seen, we need not at present discuss it. Suppose we grant, for the sake of argument, (till we can manage to get hold of Rendu's *Mémoire*; the only copy we know of, that of Principal Forbes, being at present in Switzerland)* that Rendu meant by *crevasses* something quite different from what other people mean by the word, and in fact something so very different as to make his observation almost amount to a *proof* of the more rapid motion of the centre of a glacier:—Suppose we grant this, how is it that Dr. Tyndall, who "discovered" these passages in Rendu of so "much greater importance" than those cited by Forbes, and who has been able for the last "dozen years" to have "blown" Forbes' argument on this point into "shreds, had he so willed":—how is it, we ask, that he so strangely and pointedly omitted to quote, as his most telling excerpt from Rendu, this very passage, so enormously more important (as his reading of it makes it out to be) than those he so much vaunted? Let the reader remember that Dr. Tyndall, (indirectly as usual) accuses Forbes of suppressing passages of "cardinal import." Why then did Dr. Tyndall, of set purpose, *suppress* this, according to his reading, *the most important passage of all?* Here is his answer. It needs but little comment of ours.

"The 'abrupt' termination of my quotation, and the "introduction of the 'four dots' above referred to were "simply intended to save my readers from an error into "which . . . . . Principal Forbes has unwittingly "led his biographers."

* Professor George Forbes is preparing for republication Rendu's *Mémoire*, with a translation; and with a Preface, containing, without comment, all the important facts and dates of the history of glacier discovery. [This intention has been only in part carried out.—ED.]

That is to say, the necessity for giving along with it a single sentence of explanation, prevented Dr. Tyndall from printing, in 1859, the one really novel and valuable passage of Rendu which he had discovered! For fourteen years poor Rendu has been deprived of credit for this, and even Dr. Tyndall (who seems to have been alone in his knowledge of it) has assigned to Agassiz, and (independently) to Forbes, the "conclusive estab- "lishment" of the greater central motion!

In passing from this we must again remind the reader that, even if Dr. Tyndall's defence of himself were as complete, on both of these charges under Forbes' query No. 3, as it is utterly inadequate on the one and, at the best, but lame on the other, this would in no way whatever touch the main points of Forbes' *Reply*. That document was mainly designed to show that Forbes had been systematically misrepresented by Dr. Tyndall, and more especially as to his treatment of Rendu, and Dr. Tyndall has not even attempted to answer one of the charges so made.

The concluding section of the *Reply* is singularly happy. Dr. Tyndall had complained that *in this country* certain passages of Rendu's work had been unquoted, &c., &c. Forbes asks whether any *foreign* work can be cited in which justice is done to it. "The "effectual promulgation," he says, after carefully going into the history of the question, "of Rendu's opinions "and merits came *from this country*, and through my "own writings." He then quotes (from the *Edinburgh Review*, July, 1844) Sir David Brewster's curiously prophetic anticipation, which described, *fifteen years before the* "Glaciers of the Alps" *was published*, almost exactly the course which Dr. Tyndall was there to adopt: and he concludes (after giving another telling instance of Dr. Tyndall's peculiar mode of making quotations) by giving an extract from a letter of Rendu to himself; in which the Bishop uses the following words—of themselves amply sufficient to settle for ever the whole *scientific* point at issue:—

"Votre théorie de la marche des glaciers finira par

" être la seule admise, parce qu'elle est, selon moi, la " seule vraie."

VI. *Dr. Tyndall's Article.*

In addition to the remarks we have already made on Dr. Tyndall's Article, under several of the preceding heads, a few remain to be made before we conclude for the present. We will take, in the order of their occurrence, such passages as seem to require present comment. But, before we do so, we may explain that several matters to which Dr. Tyndall has alluded, all more or less foreign to the question now before us, have been left unnoticed by us simply because they appear to have been thrown in with a view to complicating the question; and, while thus allowing Dr. Tyndall temporarily to disguise the meagreness and inadequacy of his attempt to answer *one* part (for it is but one, and that a subsidiary one) of Forbes' *Reply*, doing him the further service of confusing and entangling us in our endeavour to let the public have a clear view of the real points in debate. We have not permitted ourselves to be so entangled, and we hope that Dr. Tyndall will not in future waste valuable space by throwing in meaningless obstacles like those which we have, when we came face to face with them, found so little in our way.

Dr. Tyndall is never weary of telling us that, if he had any accusation to bring, it would not be " obscurely " indicated ;" and he has certainly managed to bear out this statement in the most unmistakable manner in one or two instances ; so forcibly, indeed, in these, that we at once, and without the least feeling of shame, acknowledge ourselves quite unable to meet him with his own weapons. In such cases, where they were of any consequence, we have preferred, if possible, to go a little farther back, and to show that there has really been no occasion for fight at all; that the matter had been irrevocably decided against Dr. Tyndall before he took the field ; or, we have endeavoured to do the best we could with what may be called (in a modern, though

perhaps not exactly in a mediæval, sense) mere "arms " of courtesy."

Dr. Tyndall quotes, from a lecture delivered by him in 1858, what he evidently wishes to be regarded as a glowing panegyric upon Forbes. Why give us this now? We complained—justly, as we have above proved—of something different from this in the *Forms of Water;* so that his quotation, even were it unmixed praise, is nothing to the purpose. But it begins with faint praise, and ends (after laudation of the mere " qualities of mind, and the scientific culture invested " (*sic*) in that excellent work") by proposing to institute a "free and frank comparison of its statements with " facts."

There is not one word in the quotation to render it certain that this last clause is not meant to imply the inaccuracy of every one of Forbes' "statements." We are told that Dr. Tyndall soon found, with regret, that such "comparison would be tolerated on one condition " alone," which was "that its results should be mere " confirmations of the views previously enunciated by " Professor Forbes." Our recollection may possibly be at fault, but it seems to us that what was not tolerated was that Forbes' statements should be brought to the test in an incomplete form, or in a form essentially different from that in which he had himself presented them. The more really "free and frank" the "com- " parison" is made, the more clearly will it be seen how completely Forbes anticipated almost everything of value which his successors claim to have discovered.

This enables us to give another very striking instance of the inconsistency of Dr. Tyndall's mode of argument. A few pages after giving his quotation, which, as we have seen, may possibly be a mere barren compliment, he speaks of Forbes' "references to Rendu, which, fre- " quent and flattering as they are, left no abiding im- " pression upon the reader's mind. By some qualifying " phrase the quotation in each case is deprived of " weight." When we read this we were curiously puzzled; it recalled so exactly the ideas which had

arisen in our minds on perusal of Dr. Tyndall's laudatory reference to Forbes' *Travels.*

With reference to Dr. Tyndall's defence of himself for putting M. Agassiz so prominently forward in connection with the discovery of purely physical properties of glaciers, we will content ourselves with an extract from a paper in the *Westminster Review* (April, 1857) of which as a whole, while entirely dissenting from its main conclusions, we cannot but remark that its general characteristic is moderation, if not always impartiality; and that it exhibits a clearness and definiteness of conception and of expression not to be found in any other writings on Dr. Tyndall's side of the question. If all controversial writings had, in as marked a manner, these characteristics, there would be an immense saving of time for more useful work. Two such combatants would feel each other's pulse, as it were, in a few moments, like skilful fencers after a few passes; or, like a couple of able chess-players, in one or two moves after the stereotyped ones.

Before we give the extract, however, we have to notice that Dr. Tyndall says "Neither in his *Travels in* "*the Alps*, nor in his *Occasional Papers*, does Princi- "pal Forbes, to my knowledge, make any reference to "this communication of Agassiz. I am far from charg- "ing him with conscious wrong, or doubting that he "justified this reticence to his own mind . . . I am "no partizan of Agassiz, but I desire to be just." Observe here that Dr. Tyndall mentions the *Travels* and the *Occasional Papers* only! He does not refer to the *Reply*, though he is in the very act of attempting to answer it, and though in § 6 of that *Reply* (a section to which we have already specially called his attention) Forbes' explanation is given! We are really curious to know whether or not there can be found a reason for this very remarkable proceeding.

Here, then, is the history; as written by an author who is obviously favourable to Dr. Tyndall.

"Among all the different theories, however, that

" propounded by the distinguished Professor of Natural " Philosophy in the University of Edinburgh has " swallowed up the rest, as the rod of Moses, in its " ophidian condition, swallowed up all the rods of the " Egyptians. Nor is this wonderful, when we remember " that from the time of De Saussure to the year 1842, " Professor J. Forbes was the only man who brought " to the investigation of the great problems presented " by glaciers, the requisite preliminary knowledge of " physical science, and the still more necessary physical " cast of intellect. Whatever view we may take of the " obligations under which the eminent author of the " 'Viscous Theory' lies to his predecessors, or to his " contemporaries, it must be admitted that the date of " the publication of his letters and travels will always " form an epoch in the history of the glacier question. " Nor will the ultimate verdict of science, as to the " truth or falsehood of some parts of the so-called vis- " cous theory, affect the claims of its propounder to the " admiration ever yielded to genius, energy, and " eloquence.

" Even apart from these broad considerations, we " must not forget that the two great facts which form " the basis whence all possible theories of glaciers must " start, were established and placed in their true light " by Professor Forbes. It may be true that Professor " Guyot discovered and described the veined structure " of glacier ice in the year 1838, but a careful con- " sideration and weighing of the documentary evidence " must, we think, convince every impartial judge, that " not only did Professor Forbes independently re-dis- " cover this structure, but that not even its original " discoverer, and still less M. Agassiz—who appears to " have forgotten all about the matter until his attention " was called to it by Professor Forbes—had any clear " conception of the real value and bearing of the fact.

" So again, it is true that M. Rendu and others had " compared the movement of a glacier to that of a more " or less viscous fluid, before Professor Forbes pro- " pounded his theory; and it seems to be a fact that

" in 1841, either during, or immediately after the visit " of Professor Forbes to the glacier of the Aar in com- " pany with M. Agassiz, the latter gentleman had made " every arrangement for ascertaining the true rate of " motion of the different parts of the glacier.

" 'Pendant notre séjour sur le glacier en 1841, M. " Agassiz détermina de concert avec M. Escher, au " moyen de l'équerre d'arpenteur, la position de cinq " blocs, en vue d'apprendre à connaître les rapports " qui existent entre les différentes parties du glacier " quant à leur mouvement, et de s'assurer si, comme on " le croyait généralement, les parties inférieures du " glacier marchent réellement plus vite que les parties " supérieures, ou bien si l'inverse a lieu. Il importait " également de s'assurer par l'expérience si les bords ont " un mouvement plus accéléré que le centre ou vice " versâ. M. Agassiz avait aligné dans ce but à travers " le glacier de l'Aar à l'hauteur de la cabane Hugi, " c'est-a-dire à environ 2,000 pieds au dessous de l'Hôtel " des Neuchâtelois, une série de pieux, rapportés à des " points fixés des bords de la vallée et plantés à une " profondeur de dix pieds dans la glace. C'était donc " en 1842, que nous pouvions espérer d'obtenir les " premiers résultats comparatifs sur le mouvement des " différentes parties du glacier dans le cours d'une " année. . . . Voici d'abord les résultats de la " série de pieux alignés à travers le glacier, mesurés le " 20 juillet, 1842. . . . Il résulte de là que la " marche des différentes parties du glacier présente une " courbe dont la convexité est tournée en bas.' *

" From this statement it appears that in the autumn " of 1841, M. Agassiz had taken all the steps for as- " certaining experimentally the rate of motion of the " different parts of a glacier, little dreaming that the " results of these proceedings would be the overthrow " of the hypothesis he then entertained, that the sides " of a glacier move faster than the middle. But even

* "*Compte Rendu des Recherches de M. Agassiz*, par E. Desor, Bibl. Univ. de Genève. 1843."

" the melancholy pleasure of refuting himself was denied " to the Swiss *savan*. In science, the race not unfre- " quently *is* to the swift; and, the northern philosopher " having betaken himself to Switzerland in June, 1842, " was enabled, by applying the delicate and accurate " process of theodolitic measurement to the small daily " movement of the glacier, to obtain, in four days, the " results for which M. Agassiz, with his comparatively " rough procedure, had had to wait a twelvemonth. " And hence, a whole fortnight before M. Agassiz in- " spected his line of stakes on the Aar glacier, namely, " on the 4th of July, 1842, we find Professor Forbes " writing, from the Mer de Glace, a letter to Professor " Jameson, in which all the great laws of glacier move- " ment are stated with accuracy and precision; and in " the two memorable letters dispatched from Chamouni " and Zermatt, in the course of the ensuing six weeks, " all the essential points of the viscous theory may be " watched, as they developed themselves in the writer's " mind out of these laws, combined with other facts. " At the end of 1842, we may say the theory was fully " formed; and though from that time to the present it " has suffered rude assaults from more than one quarter, " it has gone on waxing in strength, and finding greater " favour in men's eyes, until, at present, many of its " old opponents are converted into supporters; others ". are silenced, and the objections of the few who still " dissent seem rather verbal than real."

Dr. Tyndall says :—" Strong reasons may cause me to " revert to this question, but they must be very strong. " I would only warn my readers against the assumption, " that if I do not reply to further attack, I am unable " to reply to it." Surely no reasons can, in the nature of things, be stronger than those which must have pressed heavily on him while he wrote : for he must have felt keenly that his Article touches in no way whatever the two main points of Forbes' masterly paper, but deals (and in a very lame way too) with a mere subsidiary point.

Dr. Tyndall also says his pages "lack the complete-
"ness, and still more the strength, which I should have
"sought to confer upon them had my present position
"been forced *(sic)* upon me by Principal Forbes himself,
"instead of by his friends." His present position is one in which he has placed himself; and he has "forced" it "upon" himself by repeating, in the *Forms of Water*, after Forbes' death, charges triumphantly refuted in that *Reply* of 1860, to which, while Forbes was alive, Dr. Tyndall did not venture to answer a single word. Of course we cannot pretend to anything like the knowledge or power of Principal Forbes in a matter like this, which formed one of the main features of his whole scientific life; still we wish that Dr. Tyndall had not made so much allowance for our comparative weakness, but had "conferred" upon his Article that "com-
"pleteness" and that "strength" in both of which we have found it so sadly deficient.

For the Biographers of Principal Forbes,

P. G. TAIT.

EXTRACT FROM "FORS CLAVIGERA,"

OCTOBER, 1873 (LETTER 34).

I HAVE no space in this number of "Fors" to say what reason there is for my taking notice of this book,* or the glacier theory, in connection with the life of Scott. In the interests of general literature, it is otherwise fitting that the nature of the book itself should be pointed out.

Its nature, that is to say, so far as it has any. It seems to be written for a singular order of young people, whom, if they were older, Professor Tyndall assures them, it would give him pleasure to take up Mont Blanc; but whom he can at present invite to walk with him along the moraine from the Jardin, where "perfect steadiness of foot is necessary,—a slip would be death;" and to whom, with Mr. Hirsch, he can "confide confidently" the use of his surveying chain. It is, at all events, written for entirely ignorant people—and entirely idle ones, who cannot be got to read without being coaxed and flattered into the unusual exertion. "Here, my friend," says the Professor, at the end of his benevolently alluring pages, "our "labours close! It has been a true pleasure to me to "have you at my side so long. You have been stead-"fast and industrious throughout. . . . Steadfast, "prudent, without terror, though not at all times with-"out awe, I have found you on rock and ice. Give "me your hand—Good bye." Does the Professor count,

* *The Forms of Water.* King and Co., Cornhill. 1872.

then, upon *no* readers, but those whom he can gratify with polite expressions of this kind? Upon none who, perhaps, unsteadfast, imprudent, and very much frightened upon rock and ice, have nevertheless done their own work there, and know good work of other people's, from bad, *any*where; and true praise from false anywhere; and can detect the dishonouring of nameable and noble persons, couched under sycophancy of the nameless? He has at least had one reader, whom I can answer for, of this inconvenient sort.

It is, I am sorry to say, just forty years (some day last month) since I first saw the Bernese Alps from above Schaffhausen. Since that evening I have never let slip a chance of knowing anything definite about glaciers and their ways; and have watched the progress of knowledge, and the oscillations of theory, on the subject, with an interest not less deep, and certainly more sincere, than it would have been if my own industry had been able to advance the one, or my own ingenuity to complicate the other. But only one great step in the knowledge of glaciers has been made in all that period; and it seems the principal object of Professor Tyndall's book to conceal its having been taken, that he and his friends may get the credit, some day, of having taken it themselves.

I went to the University in 1836, and my best friend there, among the older masters, Dr. Buckland, kept me not ill-informed on my favourite subject, the geological, or crystallogical, question. Nearly everything of which Professor Tyndall informs his courageous readers, was known then, just as well as it is now. We all,—that is to say, all geologists of any standing, and their pupils,—knew that glaciers moved; that they were supplied by snow at the top of the Alps, and consumed by the heat at the bottom of them; that there were cracks all through them, and *moraines* all down them; that some of their ice was clear, and other ice opaque; that some of it was sound, and some rotten; and that streams fell into them at places called mills, and came out of them at places called grottoes.

We were, I am sorry to say, somewhat languidly content with these articles of information; we never thought of wading, "breast-deep, through snow" in search of more, and still less of "striking our theodo-" lites with the feelings of a general who had won "a small battle."* Things went on thus quietly enough. We were all puzzled to account for glacier motion, but never thought of ascertaining what the motion really was. We knew that the ice slipped over the rocks at some places, tumbled over them at others; gaped, or as people who wanted to write sublimely always said, yawned, when it was steep, and shut up again when it was level. And Mr. Charpentier wrote a thick volume to show that it moved by expansion and contraction, which I read all through, and thought extremely plausible. But none of us ever had the slightest idea of the ice's being anything but an entirely solid substance, which was to be reasoned about as capable indeed of being broken, or crushed, or pushed, or pulled in any direction, and of sliding or falling as gravity and smooth surfaces might guide it, but was always entirely rigid and brittle in its substance, like so much glass or stone.

This was the state of affairs in 1841. Professor Agassiz, of Neuchâtel, had then been some eight or ten years at work on the glaciers; had built a cabin on one of them; walked a great many times over a great many of them; described a number of their phenomena quite correctly; proposed, and in some cases performed, many ingenious experiments upon them; and indeed done almost everything that was to be done for them—except find out the one thing that we wanted to know.

As his malicious fortune would have it, he invited in that year (1841) a man of acute brains to see what he was about. The invitation was accepted. The visitor was a mathematician; and after examining the question, for discussion of which Agassiz was able to supply

* When next the reader has an opportunity of repeating Professor Tyndall's experiments (p. 92) in a wreath of dry snow, I recommend him first to try how much jumping is necessary in order to get into it, "breast-deep"; and secondly, how far he can "wade" in that dramatic position.

him with all the data except those which were essential, resolved to find out the essential ones himself.

Which in the next year (1842) he quietly did; and in 1843 solved the problem of glacier motion for ever—announcing, to everybody's astonishment, and to the extreme disgust and mortification of all glacier students,—including my poor self (not the least envious, I fancy, though with as little right to be envious as any one),—that glaciers were not solid bodies at all, but semi-liquid ones, and ran down in their beds like so much treacle.

"Cela saute aux yeux," we all said, as soon as we were told; and I well remember the intense mortification of first looking down on the dirt bands of the Mer-de-Glace, from the foot of the Little Charmoz, after I had read Principal Forbes' book. That we never should have seen them before!—so palpable, so inevitable now, with every inch of the ice's motion kept record of, in them, for centuries, and every curve pencilled in dark, so that no river eddies, no festooned fall of sweeping cascade, could be more conclusive in proof of the flowing current. And of course it flowed;—how else could it have moved but by a series of catastrophes? Everything explained, now, by one shrewd and clear-sighted man's work for a couple of summer months; and what asses we had all been!

But fancy the feelings of poor Agassiz in his Hotel des Neuchâtelois! To have had the thing under his nose for ten years, and missed it! There is nothing in the annals of scientific mischance—(perhaps the truer word would be scientific dulness)—to match it; certainly it would be difficult for provocation to be more bitter,—at least, for a man who thinks, as most of our foolish modern scientific men do think, that there is no good in knowing anything for its own sake, but only in being the first to find it out.

Nor am I prepared altogether to justify Forbes in his method of proceeding, except on the terms of battle which men of science have laid down for themselves. Here is a man has been ten years at his diggings; has

trenched here, and bored there, and been over all the ground again and again, except just where the nugget is. He asks one to dinner,—and one has an eye for the run of a stream; one does a little bit of pickaxing in the afternoon on one's own account,—and walks off with his nugget. It is hard.

Still, in strictness, it is perfectly fair. The newcomer, spade on shoulder, does not understand, when he accepts the invitation to dinner, that he must not dig,—or must give all he gets to his host. The luck is his, and the old pitsman may very excusably growl and swear at him a little; but has no real right to quarrel with him,—still less to say that his nugget is copper, and try to make everybody else think so too.

Alas, it was too clear that this Forbes' nugget was not copper. The importance of the discovery was shown in nothing so much as in the spite of Agassiz and his friends. The really valuable work of Agassiz on the glaciers was itself disgraced, and made a monument to the genius of Forbes, by the irrelevant spite with which every page was stained in which his name could be introduced. Mr. Desor found consolation in describing the cowardice of the Ecossais on the top of the Jungfrau; and all the ingenuity and plausibility of Professor Tyndall have been employed, since the death of Forbes, to diminish the lustre of his discovery, and divide the credit of it.

To diminish the lustre, observe, is the fatallest wrong; by diminishing its distinctness. At the end of this last book of his, in the four hundred and tenth of the sapient sentences which he numbers with paternal care, he still denies, as far as he dares, the essential point of Forbes' discovery; denies it interrogatively, leaving the reader to consider the whole subject as yet open to discussion,—only to be conclusively determined by—Professor Tyndall and his friends. "Ice splits," he says, "if you strike a pointed pricker into it; fissures, "narrow and profound, may be traced for hundreds of "yards through the ice. Did the ice possess even a "very small modicum of that power of stretching

" which is characteristic of a viscous substance, 'such " crevasses could not be formed.'" Professor Tyndall presumably never having seen a crack in clay, nor in shoe leather, nor in a dish of jelly set down with a jerk; nor, in the very wax he himself squeezed flat to show the nature of cleavage—understood that the cleavage meant the multiplication of fissure!

And the book pretends to be so explanatory, too, to his young friends!—explanatory of the use of the theodolite, of the nature of presence of mind, of the dependence of enjoyment of scenery upon honest labour, of the necessity that in science, " thought, as far as " possible, should be wedded to fact," and of the propriety of their becoming older and better informed before they unqualifiedly accept his opinion of the labours of Rendu!

But the one thing which, after following him through the edification of his four hundred and ten sentences, they had a right to have explained to them—the one thing that will puzzle them if ever they see a glacier, "*how* the centre flows past the sides, and the top flows over the bottom," the Professor does *not* explain; but only assures them of the attention which the experiments of Mr. Mathews, Mr. Froude, and above all Signor Bianconi, on that subject, " will doubtless receive at a future time."

The readers of " Fors " may imagine they have nothing to do with personal questions of this kind. But they have no conception of the degree in which general science is corrupted and retarded by these jealousies of the schools; nor how important it is to the cause of all true education, that the criminal indulgence of them should be chastised. Criminal is a strong word, but an entirely just one. I am not likely to overrate the abilities of Professor Tyndall; but he had at least intelligence enough to know that his dispute of the statements of Forbes, by quibbling on the word " viscous," was as uncandid as it was unscholarly; and it retarded the advance of glacier science for at least ten years. It was unscholarly, because no other single word existed

in the English language which Forbes could have used instead ; and uncandid, because Professor Tyndall knew perfectly well that Forbes was aware of the difference between ice and glue, without any need for experiments on them at the Royal Institution. Forbes said that the mass of glacier ice was viscous, though an inch of ice was not, just as it may be said, with absolute truth, that a cartload of fresh-caught herring is liquid, though a single herring is not. And the absurdity, as well as the iniquity of the Professor's wilful avoidance of this gist of the whole debate is consummated in this last book, in which, though its title is *The Forms of Water*, he actually never traces the transformation of snow into glacier ice at all—(blundering by the way, in consequence, as to the use of one of the commonest words in Savoyard French, *névé).* For there are three great "forms of water" by which the Alps are sheeted, —one is snow ; another is glacier ice ; the third is *névé,* which is the transitional substance between one and the other. And there is not a syllable from the beginning of the book to the end, on the subject of this change, the nature of which is quite the first point to be determined in the analysis of glacier motion.

* * * * *

THE incidental passage in "Fors," hastily written, on a contemptible issue, does not in the least indicate my sense of the real position of James Forbes among the men of his day. I have asked his son's permission to add a few words expressive of my deeper feelings.

For indeed it seems to me that all these questions as to priority of ideas or observations are beneath debate among noble persons. What a man like Forbes first noticed, or demonstrated, is of no real moment to his memory. What he was, and how he taught, is of consummate moment. The actuality of his personal power, the sincerity and wisdom of his constant teaching, need no applause from the love they justly gained, and can sustain no diminution from hostility ; for their proper

honour is in their usefulness. To a man of no essential power, the accident of a discovery is apotheosis; to *him*, the former knowledge of all the sages of earth is as though it were not; he calls the ants of his own generation round him, to observe how he flourishes in his tiny forceps the grain of sand he has imposed upon Pelion. But from all such vindication of the claims of Forbes to mere discovery, I, his friend, would, for my own part, proudly abstain. I do not in the slightest degree care whether he was the first to see this, or the first to say that, or how many common persons had seen or said as much before. What I rejoice in knowing of him is that he had clear eyes and open heart for all things and deeds appertaining to his life; that whatever he discerned, was discerned impartially; whatever he said, was said securely; and that in all functions of thought, experiment, or communication, he was sure to be eventually right, and serviceable to mankind, whether out of the treasury of eternal knowledge he brought forth things new or old.

This is the essential difference between the work of men of true genius and the agitation of temporary and popular power. The first root of their usefulness is in subjection of their vanity to their purpose. It is not in calibre or range of intellect that men vitally differ; every phase of mental character has honourable office; but the vital difference between the strong and weak—or let me say rather, between the availing and the valueless intelligence—is in the relation of the love of self to the love of the subject or occupation. Many an Alpine traveller, many a busy man of science, nowadays, volubly represent to us their pleasure in the Alps; but I scarcely recognize one who would not willingly see them all ground down into gravel, on condition of his being the first to exhibit a pebble of it at the Royal Institution. Whereas it may be felt in any single page of Forbes's writing, or De Saussure's, that they love crag and glacier for their own sake's sake; that they question their secrets in reverent and solemn thirst: not

at all that they may communicate them at breakfast to the readers of the Daily News,—and that, although there were no news, no institutions, no leading articles, no medals, no money, and no mob, in the world, these men would still labour, and be glad, though all their knowledge was to rest with them at last in the silence of the snows, or only to be taught to peasant children sitting in the shade of pines.

And whatever Forbes did or spoke during his noble life was in this manner patiently and permanently true. The passage of his lectures in which he shows the folly of Macaulay's assertion, that "The giants of one generation are the pigmies of the next," beautiful in itself, is more interesting yet in the indication it gives of the general grasp and melodious tone of Forbes's *reverent* intellect, as opposed to the discordant insolence of modernism. His mind grew and took colour like an Alpine flower, rooted on rock, and perennial in flower; while Macaulay's swelled like a puff-ball in an unwholesome pasture, and projected itself far round in deleterious dust.

I had intended saying a few words more touching the difference in temper, and probity of heart, between Forbes and Agassiz, as manifested in the documents now laid before the public. And as far as my own feelings are concerned, the death of Agassiz would not have caused my withholding a word. For in all utterance of blame or praise, I have striven always to be kind to the living—just to the dead. But in deference to the wish of the son of Forbes, I keep silence: I willingly leave sentence to be pronounced by time, above their two graves.

JOHN RUSKIN.

The following letters, one from Forbes to myself written ten years ago, and the other from one of his pupils, received by me a few weeks since, must however take their due place among the other evidence on which such judgement is to be given. J. R.

"ST. ANDREWS, *2nd Dec., 1864.*

"MY DEAR SIR—Having almost retired from the din "of controversy, it is a pleasureable surprise to me to "find now and then some old friend who has not "forgotten me, and who has still spirit and fidelity "enough to break a lance in my favour.

"For about three years I have felt disheartened and "hopeless as to stemming the popular tide of prepossessions against my "Theory of Glaciers," or, I should "rather say, against me personally as its author. The "article in the 'Quarterly,' seemed to me to complete "the triumph of Tyndall within the limits of his influence. Its dulness and stupid reiteration of exploded statements seemed to me to give the best "promise of its speedy oblivion. Advancing years "and a permanently depressed state of health have "taken the edge off the bitterness which the injustice "I have experienced caused me during many years. "But, as I said, the old fire revives within me when "I see any one willing and courageous, like you, to "remember an old friend, and to show that you do so.

"I have just read ———'s paper in the *Phil. "Mag.*, for October, which is better written than he "usually does, and he makes some good points. But "what amuses me is the *necessity* to which glacialists "are driven (whatever opinions they may profess) to "treat glaciers as plastic, in the most uncompromising "sense of the term.

"I hope your health is good and that you still enjoy "frequent trips to Switzerland. I am so bad a traveller, now, that even the railway journey is quite a "barrier, especially were my family to accompany me. "I hear much of the increased obstacles to large parties "moving about since I was last abroad, and the utterly "vulgarized state to which Chamouni is reduced.

"Ever yours sincerely and obliged,

(Signed) "JAMES D. FORBES."

The following are portions of a letter from Mr. Robert B. Watson, dated—

"MADEIRA, *Dec.* 13, 1873.

"THE Nat. Phil. Class was an essential preparation "for the study of Divinity in the Free Church of "Scotland, of which I am now a minister. Thus I "attended Forbes. That was in the session '44-5. "Glaciers, of course, came prominently into the course, "but of Agassiz we learned only as a great and "honoured name. In January, 1846 (I think on the "2nd of the month), going from Geneva to Berne in "bitter cold and deep snow, alone in the diligence, "there entered to me at Neuchâtel, as the early dark "settled down upon us, a cheery fellow-traveller, who "drew out the last moments in eager talk with a parting "friend—one with a certain stamp of greatness on him "and their talk was all of glaciers. On that subject— "I kindled, and when at length Desor, my new fellow- "traveller, told me that the Agassiz of whom I spoke "was none other than he who had stood beside me "at the coach door, *all my boyish enthusiasm was "stirred,** and I told all I had learned of him, and from "whom. Then it was Desor told me, he and others of "Agassiz' friends, their leader himself, about to start "for America, being unable to come, were going to the "Aar Glacier, to measure for the first time, the "actual movement of the ice. Very soon it was arran- "ged that I should go too. Next day we were joined "by M. Dolfuss-Ausset (Papa Dolfuss) from Mulhouse. "The following day we reached Meyringen, and "the day after we walked to the Grimsel. There we "spent several days in bright fierce cold, making "various theodolite measurements at many points, "digging a deep hole into the glacier beyond the "influence of superficial cold there, by coloured water "to test the percolation susceptibility of the ice.

* *The italics are mine.* I think this incidental and naive proof of the way in which Forbes had spoken of Agassiz to his class, of the greatest value and beautiful interest. J. R.

"Desor communicated the results to a Berne paper; "probably they have been published elsewhere, but "they amounted to little more than was known be- "fore, viz., that the ice throughout, even in winter, "was drenched with water; and that the movement "was as regular from day to day, though a little slower "than in summer.

"Forgive these personal details—at least I have not "thrust them on you, but they serve to illustrate these "two points—1st, that Forbes taught us to reverence "Agassiz; and 2nd, that Forbes' theory of viscosity "being the final explanation of glacier motion forced "itself on me, in spite of much concurring to the con- "trary, and specially of my being taught Agassiz' views "*in situ*, and by his own friends. Neither then or "since could I make out what Agassiz' antagonistic "view was, and time has only matured the conviction "that when Forbes uttered the word 'viscosity,' he "had said the very last that could be said on the "subject; and that Thomson's experiments on melt- "ing under pressure,* and regelation, explain the "manner of the viscosity—the manner not the fact. "With Rendu it was a guess among guesses too,— "with others it was a poetical metaphor, that a glacier "flowed like a river. Forbes proved that it was a "fact, and Thomson confirmed his proof by showing "whence viscosity comes."

* Professor James Thomson's later explanation (apparently overlooked by Professor Tyndall and others) was by melting under pressures *tending to change of form*, and solidifying of the water freed from those pressures.—ED.

EXTRACT

FROM

PRINCIPAL FORBES' REPLY TO CERTAIN PASSAGES IN PROFESSOR TYNDALL'S "GLACIERS OF THE ALPS."

[Published in 1860, and reprinted in full as Appendix A to the *Life and Letters of James David Forbes.*]

§ 4. *References to Rendu in my "Travels in the Alps" (1843), and in my later publications.*

The following extracts from my *Travels in the Alps* will speak for themselves. The pages referred to are those of the first edition (published in July, 1843). No alteration whatever was made in these extracts in the second edition (1845), only the pages where a few of the later ones occur are slightly different.

(a) Travels, pp. 28, 29.—" . . . In the writings of Agassiz, Godefroy, De Charpentier, and Rendu, devoted exclusively to glaciers, and published in 1840 and 1841, there is an equal silence as to the real nature of glacier structure, &c." *

(b) Travels, p. 127.—" Ebel gravely affirms[1] that the glaciers of Chamouni advance at the rate of 14 feet a year, and those of Grindelwald 25 feet a year; whereas, as we shall see, such spaces are actually traversed by

[1] "Guide du Voyageur, art. *Glacier.*"

* [Professor Tyndall (p. 301) ascribes to Rendu an allusion to the veined structure. A reference to p. 60 of the *Théorie,* however, must satisfy any impartial person that he is speaking of the true stratification of the *névé,* as would have been apparent had Professor Tyndall not stopped short in his quotation. After the word "snow" in his citation, this passage follows, identifying the description with those of De Saussure and other older writers, applied to the higher glaciers: "Il y a dans l'ensemble de grandes et de petites assises. Les premières représentent sans doute les années, et les secondes représentent peut-être une saison, un jour de pluie, une chute de neige, un violent coup de soleil."—*Rendu,* p. 61. This is evidently no account of the veined structure. (1860).]

most glaciers in the course of a few days. This statement is quoted by Captain Hall[1] and other recent writers, and even by M. Rendu (now Bishop of Annécy), the author of a most ingenious paper on glaciers, too little known."[2]

[1] "Patchwork, i. 109. [2] Mem. de la Société Académique de Savoie, x. 95."

(c) Travels, p. 128.—"M. Rendu seems to have been more aware of the importance of the determination of the rate of motion of glaciers than any other author; but the best information which he could collect in 1841 did not much tend to clear up his doubts. He gives the following rates of motion of the Mer de Glace, or Glacier des Bois, without being able to decide which is the most trustworthy: 242 feet per annum; 442 feet per annum; a foot a day; 400 feet per annum; and 40 feet per annum, or *one-tenth* of the last!—a difference which he attributes to the different rates of motion of the centre and the sides."[1]

[1] "Mémoires, &c. x. 95."

We shall see below (page 16) that Professor Tyndall, in citing the preceding passage from my *Travels,* has made two important omissions.

(d) Travels, p. 356.—Motto or heading to Chapter XXI. [which is entitled "AN ATTEMPT TO EXPLAIN THE LEADING PHENOMENA OF GLACIERS."]—'Rien ne me 'paraît plus clairement demontré que le mouvement pro- 'gressif des glaciers vers le bas de la vallée, et rien en 'même temps ne me semble plus difficile à concevoir 'que la manière dont s'exécute ce mouvement silent, 'si inégal, que s'exécute sur des pentes différentes, sur 'un sol garni d'aspérités, et dans des canaux dont la 'largeur varie à chaque instant. C'est là, selon moi, 'le phénomène le moins explicable des glaciers. Marche- 't-il ensemble comme un bloc de marbre sur un plan 'incliné? Avance-t-il par parties brisées comme les 'cailloux qui se suivent dans les couloirs des montagnes? 'S'affaisse-t-il sur lui-même pour couler le long des 'pentes, comme le ferait une lave à la fois ductile et

'liquide? Les parties qui se detachent vers les pentes 'rapides suffisent-elles à imprimer du mouvement à 'celles qui reposent sur une surface horizontale? Je 'l'ignore. Peut-être encore pourrait on dire que dans 'les grands froids l'eau que remplit les nombreuses 'crevasses transversales du glacier venant à se congeler, 'prend son accroissement de volume ordinaire, pousse 'les parois qui la contiennent, et produit ainsi un 'mouvement vers le bas du canal d'écoulement.'— RENDU, *Théorie des Glaciers*, p. 93.

(e) Travels, p. 367.—"When a glacier passes from a narrow gorge into a wide valley, it spreads itself, in accommodation to its new circumstances, as a viscous substance would do; and when embayed between rocks, it finds its outlet through a narrower channel than that by which it entered. This remarkable feature of glacier motion, already several times adverted to, had not been brought prominently forward until stated by M. Rendu, now Bishop of Annécy, who has described it very clearly in these words: 'Il y a une foule de faits qui 'sembleraient faire croire que la substance des glaciers 'jouit d'une espèce de ductilité qui lui permet de se 'modeler sur la localité qu'elle occupe, de s'amincir, de 'se renfler, de se rétrécir, et de s'étendre, comme le 'ferait une pâte molle. Cependant, quand on agit sur 'un morceau de glace, qu'on le frappe, on lui trouve 'une rigidité qui est en opposition directe avec les ap-'parences dont nous venons de parler. Peut-être que 'les expériences faites sur de plus grandes masses don-'neraient d'autres résultats."[1] Now it is by observa-

[1] "*Théorie des Glaciers de la Savoie*, p. 84. Whilst I am anxious to show how far the sagacious views of M. Rendu coincide with, as they also preceded my own, it is fair to mention, that all my experiments were made, and indeed by far the greater part of the present volume was written, before I succeeded in obtaining access to M. Rendu's work, in the tenth volume of the Memoir of the Academy of Chambéry, which I owe at length to the kindness of the right reverend author."*

*[I have explained already (page 9), that though I had cursorily seen M. Rendu's book in the possession of a friend, I never had access to it for consultation, either while deducing my theory from observations on the glaciers themselves, or afterwards when elaborating it at home, until the time above referred to, which was probably in February, 1843. (1860).]

tions on the glacier itself that we can best make experiments on *great masses* of ice, as here suggested."

(*f*) *Travels*, page 382.—"The idea of comparing a glacier to a river is anything but new, and I would not be supposed to claim that comparison or analogy as an original one. Something very like the conception of fluid motion seems to have been in the minds of several writers, although I was not aware of it at the time that I made my theory. In particular, M. Rendu, whose mechanical views are in many respects more precise than those of his predecessors or contemporaries, speaks of the 'glaciers d'écoulement' as distinct from 'glaciers reservoirs;' and in the quotation at the head of this chapter, he evidently contemplates the *possibility* of the mutual pressures of the parts overcoming the rigidity.[1] He is the only writer of the Glacier school who has insisted on the plasticity of the ice, shown by moulding itself to the endlessly varying form and section of its bed; and he is also opposed to his leading contemporaries in his conjecture that the centre of the ice-stream would be found to move fastest. But M. Rendu has the candour not to treat his ingenious speculations as leading to any certain result, not being founded on experiments worthy of confidence. 'The fact of the motion exists,' he says; 'the progression of glaciers is demonstrated, but the manner of it is *entirely unknown*. Perhaps by long observations and well made experiments on ice and snow, we may be able to apprehend it, but these first elements are still wanting.'[2]" . . . [Here follows a quotation from Captain Basil Hall.] "But such speculations could not pass into a theory until supported by the definite facts of which M. Rendu deplores the want."

[1] "See also page 107 of his work for a comparison between a glacier and a river."

[2] "'Le fait du mouvement existe, la progression des glaciers est demontrée; mais le mode est entièrement inconnu. Peut-être avec de longues observations, des expériences bien faites sur la glace et la neige, viendra-t-on à bout de le saisir: mais ces premiers éléments nous manquent encore.'"

(*g*) *Travels*, p. 385.—"I have no doubt, however,

that the convex surface of the glacier (which resembles that of mercury in a barometer tube), is due to this hydrostatic pressure acting upwards with most energy near the centre. It is the 'renflement' of Rendu, the 'surface bombée' of Agassiz."

Such are the quotations from and references to M. Rendu in the work which embodied the results of my own experiments and speculations. In my later writings I did not suffer the bishop's name to drop out of sight.

(*h*) *Eighth Letter on Glaciers*, 1844 (reprinted, 1859, in *Occasional Papers*, &c., p. 62), I say: "Facts like this seem to show with evidence, what intelligent men, such as Bishop Rendu, had only supposed previously to the first exact measures in 1842, that the ice of glaciers, rigid as it appears, has, in fact, a certain 'ductility' or 'viscosity' which permits it to model itself to the ground over which it is forced by gravity," &c.

(*i*) Paper in *Philosophical Transactions* for 1846 (read 1845; reprinted, 1859, in *Occasional Papers*, &c., p. 84.)—"M. Rendu, Bishop of Annécy, in his excellent Essay on Glaciers, refers in one passage (and I believe in one only) to the possible analogy with a lava stream, '[le glacier] s'affaisse-t-il sur lui-même pour couler le long des pentes comme le ferait une lave à la fois ductile et liquide ?[1]"

[1] "Théorie des Glaciers. Mém. de l'Academie de Savoie, tome x. p. 93, published in 1841."

(*k*) Paper in *Phil. Trans.* 1846 (*Occas. Papers*, p. 160).—"Still less could I have anticipated that when the plastic changes of form had been measured and compared, and calculated, and mapped, and confirmed by independent observers, that we should still have had men of science appealing to the fragility of an icicle as an unanswerable argument! More philosopical, surely, was the appeal of the Bishop of Annécy, from what we already know to what we may one day learn

if willing to be taught. 'Quand on agit sur un 'morceau de glace, qu'on le frappe, on lui trouve une 'rigidité qui est en opposition directe avec les appa- 'rences dont nous venons de parler. *Peut-être que les 'expériences faites sur de plus grandes masses donner- 'aient d'autres résultats.*[1]'"

[1] "Théorie des Glaciers de la Savoie, p. 84; quoted in my Travels, p. 367, second edition."

(*l*) *Thirteenth Letter on Glaciers*, 1846 (reprinted, 1859, *Occasional Papers*, p. 201).—"Bishop Rendu, whom I had the pleasure of visiting at Annécy" [in 1846], "remarked a familiar circumstance which illustrates the same thing. We often see, in the coldest weather, that opaque snow is converted into translucent ice by the sliding of boys on its surface; friction and pressure alone, without the slightest thaw, effect the change which must take place still more readily in a glacier," &c.*

I leave these extracts to the consideration of the impartial reader, that he may decide, by a comparison of them with the extracts in Professor Tyndall's work, —or, still better, with Rendu's Essay itself (where, of course, these sagacious views are mixed with a certain alloy of ingenious but inaccurate conjecture)—whether they do not constitute an adequate and impartial recognition of the Bishop's *Théorie*, and at the same time invite and facilitate reference to it.

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* [Had I been aware of the following passage in Rendu's *Théorie*, p. 75, quoted by Professor Tyndall (p. 301), I would certainly have cited it:—"D'où [*i.e.*, from an observation by De Saussure on the Seracs] l'on peut conclure que le temps favorisant l'action de l'affinité et en même temps la pression des couches les unes sur les autres, rapprochent les petits cristaux qui forment la neige, et en les amenant au contact, les font passer à l'état de glace." Nor did the Bishop refer me to his work when he made his remark about "les petits polissons," as he called them. (1860.)]

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CHAPTER VIII.

OF THE MOTION OF STREAM GLACIERS.

ALTHOUGH most authors who have spoken of the lower glaciers have sufficiently false notions as to their origin and their formation, all, nevertheless, agree that they have a movement of translation which makes them advance towards the base of the valleys; but, the moment they would instruct us as to the nature and quantity of these movements, they fall into vagueness, and often even into absurdity. In fact *there* lies, in my opinion, the true Gordian knot. The fact of motion exists, the progression of glaciers is demonstrated; but the mode of motion is entirely unknown. Perhaps with long observations, with experiments upon ice and snow carefully made, we shall succeed in grasping it; but we are still in want of these first elements.

Glaciers have two kinds of motion, the one instantaneous, and the other insensible. If in its course the

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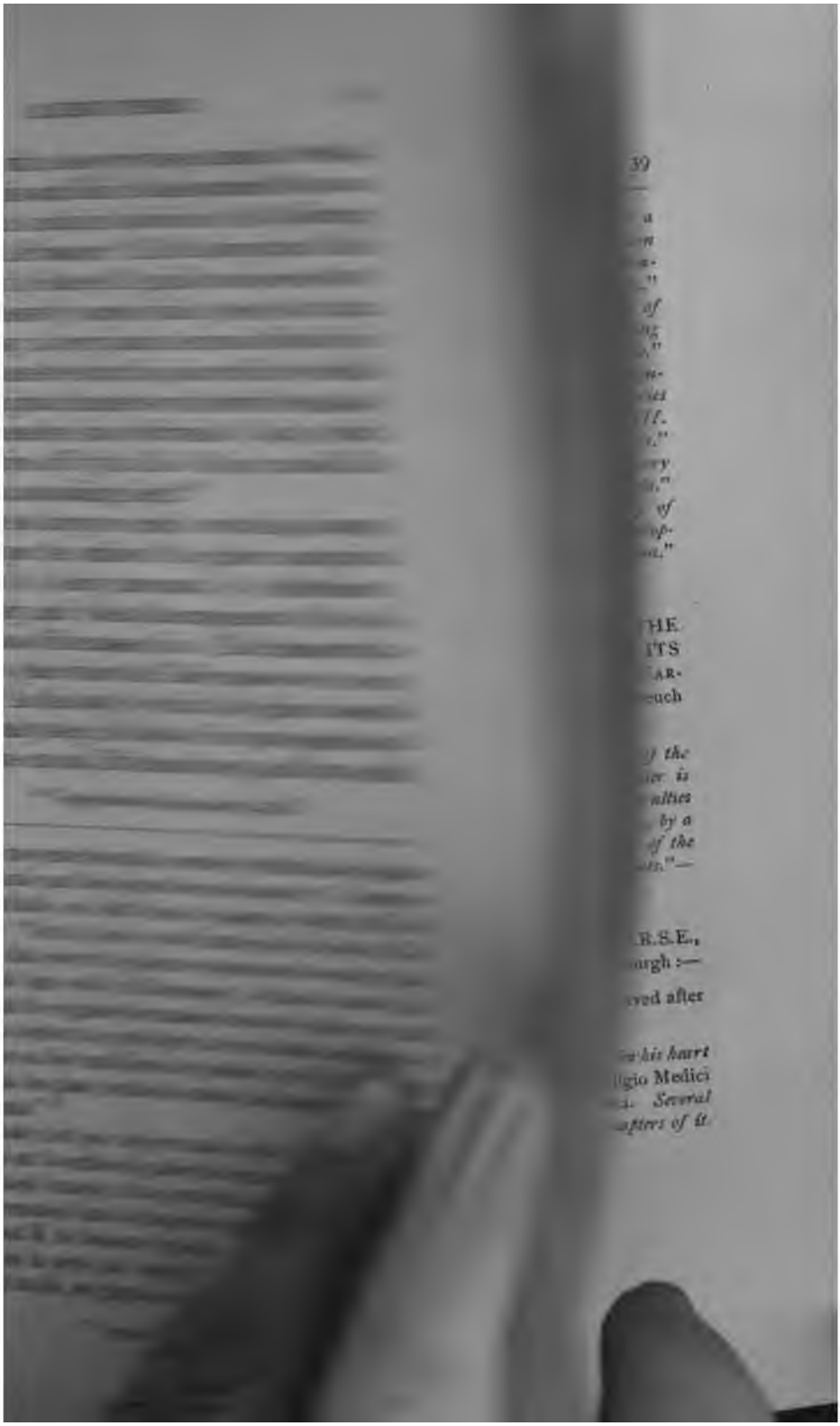
CHAPITRE VIII.

DU MOUVEMENT DES GLACIERS D'ÉCOULEMENT.

Quoique la plupart des auteurs qui ont parlé des glaciers inférieurs aient sur leur origine et leur formation des idées assez fausses, tous cependant conviennent qu'il existe pour eux un mouvement de transport qui les fait avancer vers le fond des vallées; mais dès l'instant où ils veulent faire connaître la nature et la quantité de ces mouvements, ils tombent dans le vague et souvent même dans le ridicule. En effet, c'est là, selon moi, le véritable nœud gordien. Le fait du mouvement existe, la progression des glaciers est démontrée; mais le mode est entièrement inconnu. Peut-être avec de longues observations, des expériences bien faites sur la glace et la neige viendra-t-on à bout de le saisir; mais ces premiers éléments nous manquent encore.

Il y a dans les glaciers deux espèces de mouvement, l'instantané et l'autre insensible. Si dans son cours le



Wilson—*continued.*

These fragments being in most cases like finished gems waiting to be set, some of them are now given in a collected form to his friends and the public. In living remembrance of his purpose, the name chosen by himself has been adopted, although the original design can be but very faintly represented." *The Contents of the volume are:*—"*Chemistry and Natural Theology.*" "*The Chemistry of the Stars; an Argument touching the Stars and their Inhabitants.*" "*Chemical Final Causes; as illustrated by the presence of Phosphorus, Nitrogen, and Iron in the Higher Sentient Organisms.*" "*Robert Boyle.*" "*Wollaston.*" "*Life and Discoveries of Dalton.*" "*Thoughts on the Resurrection; an Address to Medical Students.*" "*A more fascinating volume,*" *the* Spectator *says,* "*has seldom fallen into our hands.*" *The* Freeman *says:* "*These papers are all valuable and deeply interesting. The production of a profound thinker, a suggestive and eloquent writer, and a man whose piety and genius went hand in hand.*"

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